

# Test Results and Modeling of the Honda Insight and Toyota Prius

**Kenneth J. Kelly**

*Senior Engineer, Vehicle Systems Analysis  
National Renewable Energy Laboratory*

September 2001



*NREL, CENTER FOR TRANSPORTATION TECHNOLOGIES AND SYSTEMS*

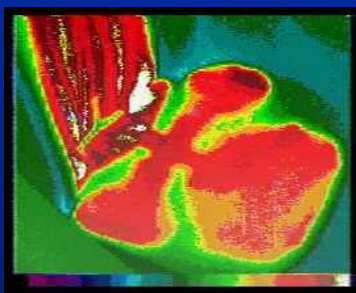


# NREL Vehicle Testing and Modeling

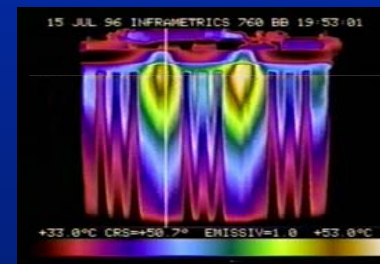
## *Interdisciplinary*



Vehicle Systems Analysis



Vehicle Climate Control



Battery Thermal Management



NREL, CENTER FOR TRANSPORTATION TECHNOLOGIES AND SYSTEMS



# Vehicle Testing Objectives

Measure the impact of air-conditioning on fuel economy and emissions

Study the behavior of the battery pack under various conditions

Develop temperature dependent battery pack model(s) for ADVISOR

Model correlation and development of accurate ADVISOR vehicle model





# *NREL's Vehicle Testing Partner:* **Environmental Testing Corp (ETC)**

Private emissions certification and R&D laboratory

Located 30 minutes from NREL in Aurora, Colorado

Key ETC customer: Daimler/Chrysler (*on-site testing presence*)

Customers Served in 2000 include:

*Ford, Daimler/Chrysler, GM, Volvo, Jaguar, Hyundai, Isuzu*

Recognized by EPA for High Altitude Emissions Certification

Previous NREL/DOE Experience testing Alternative Fuel Vehicles



NREL, CENTER

TECHNOLOGIES AND SYSTEMS



# Environmental Testing Corp (ETC) : Capabilities

- 40,000 sq ft (3700 m<sup>2</sup>) test facility on 5 acres
- Emissions Certification and Fuel Economy
  - *Four independent, temperature-controlled chassis test cells (-45 to 45 C) - including 48" electric dynamometer*
  - *bag, modal and second-by-second analysis*
  - *chemical analysis laboratory*
  - *user defined driving cycles and temperatures*
  - *catalyst efficiency*
  - *diesel particulate*
  - *customizable data acquisition*
- Evaporative Emissions, Running Loss, and On-Board Refueling Vapor Recovery (ORVR)
- Engine Dynamometer Testing
- Drivers Aid and Dynamometer Control Software





# Vehicle Testing Data Acquisition

Battery temperatures, voltages,  
and currents (20 Hz)

- 30 cell temperatures
- 10 cell voltages
- inverter current
- auxiliary load current

Cabin temperatures

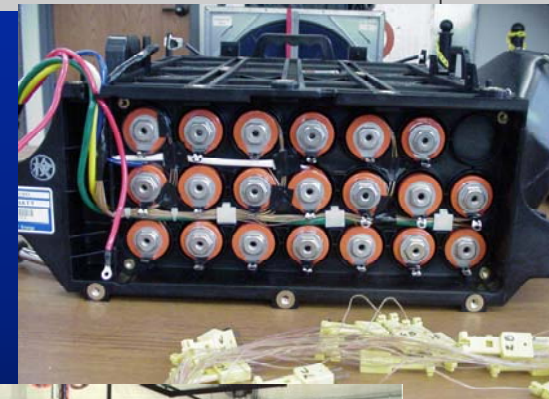
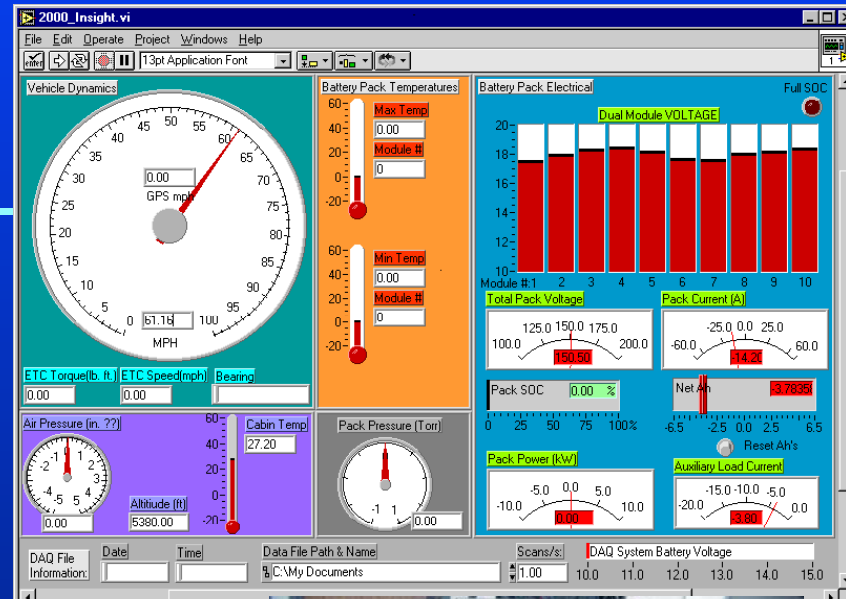
- driver, passenger, roof  
console

Vehicle Operating Parameters

- engine speed, map,  
vehicle speed, throttle  
position, engine coolant,  
intake air temp, O<sub>2</sub>

Emissions Data

(20Hz, bag, and modal analysis)



NREL, CENTER FOR TRANSPORTATION



# Vehicle Testing

## *Test Procedures*

### Chassis Dynamometer Test Procedures

- *FTP-75*
- *US06 (0, 20, 40 degrees C)*
- *SC03 (95 degrees F, with and without A/C)*
- *HWFET*

### On-Road Testing

- *Acceleration Tests*
- *City Driving Cycles (AC on/off)*
- *Highway Driving Cycles (AC on/off)*
- *Mountain Driving*

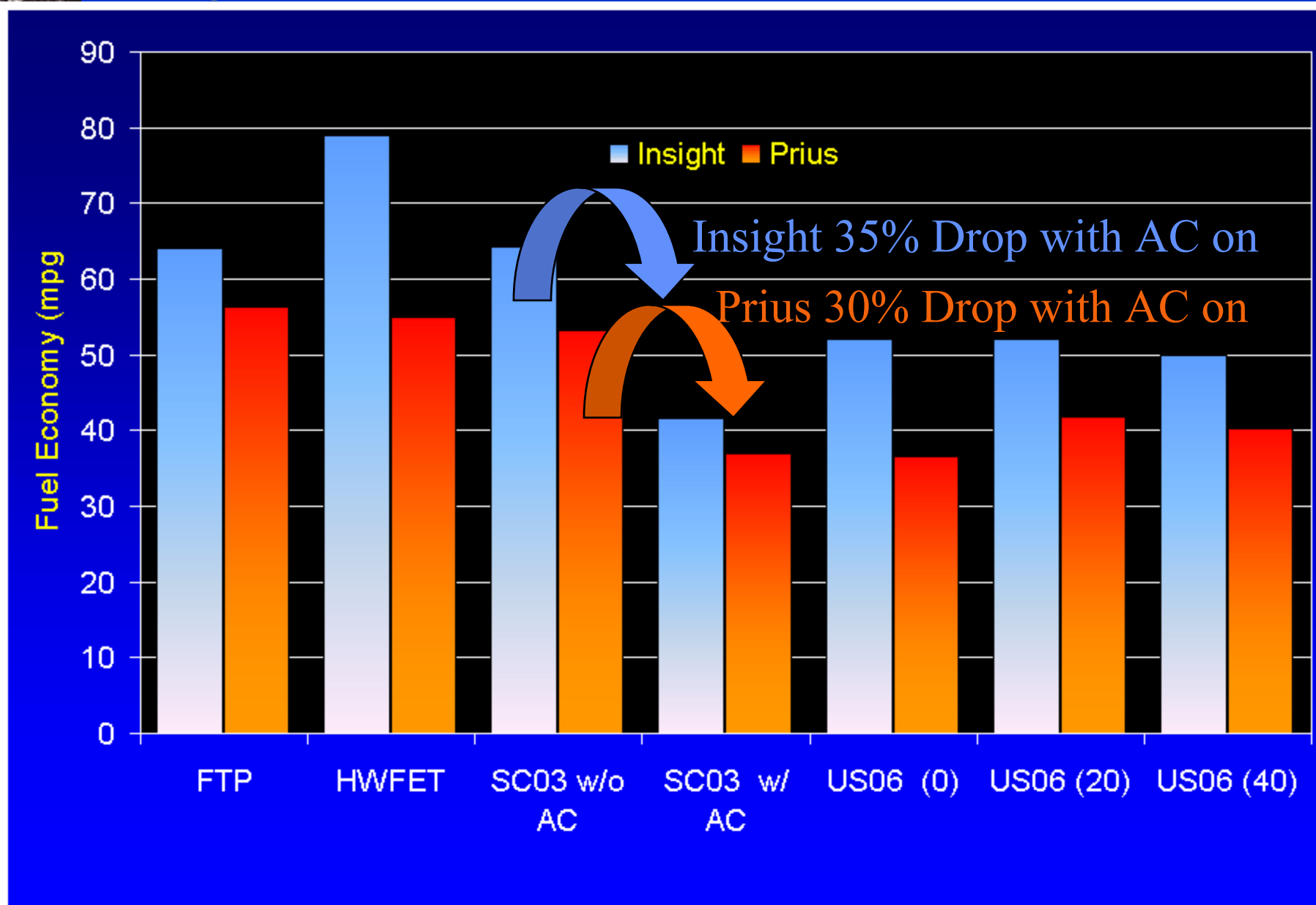
### Off-board Battery Testing

- Scheduled to begin in December '00
- ABC 150 Pack Testing
  - charge resistance, pulse power,
  - Ah capacity, driving profiles
- Calorimeter Testing
- Airflow testing



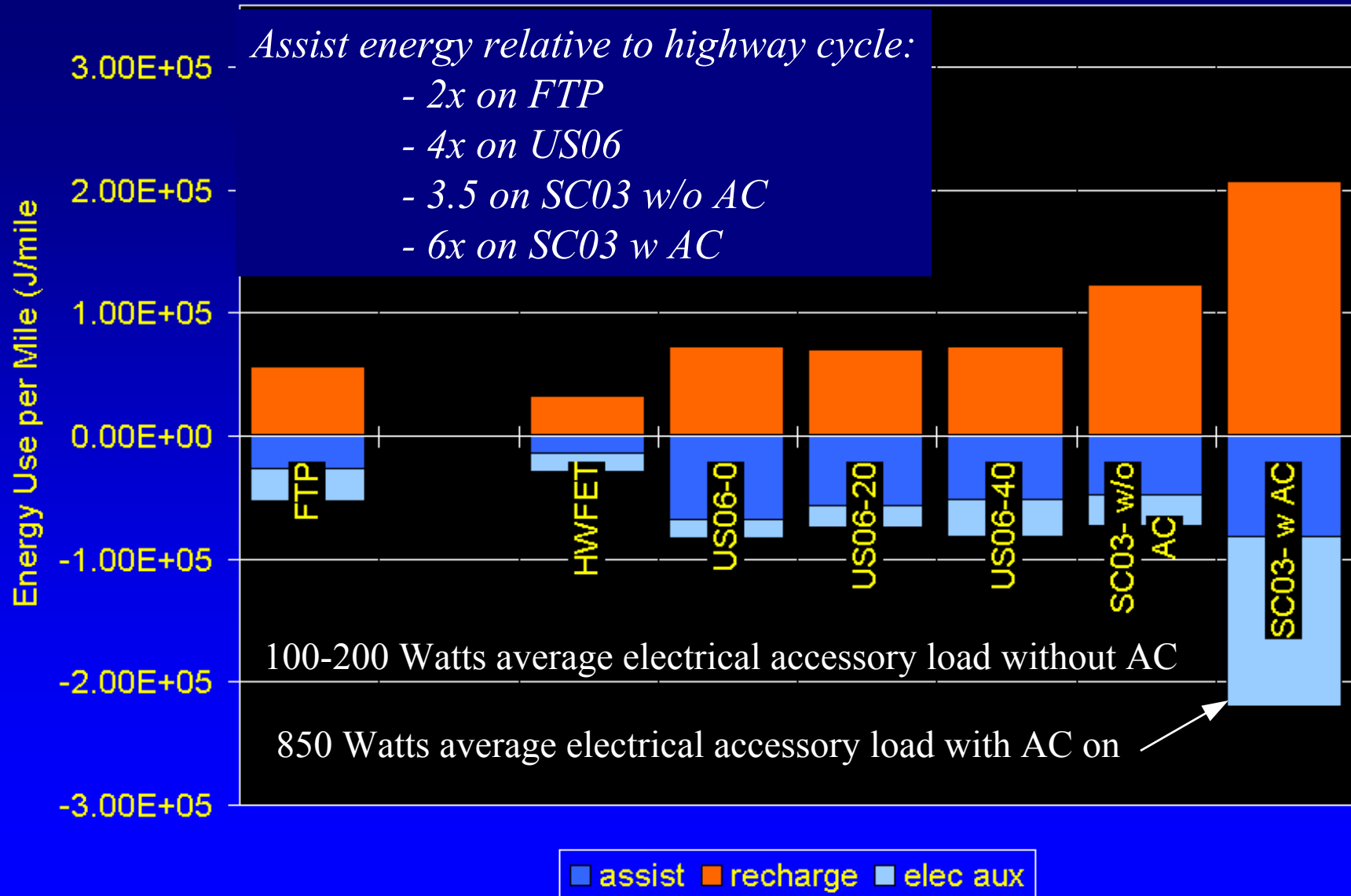
# Dynamometer Measured Fuel Economy

## *Insight and Prius*

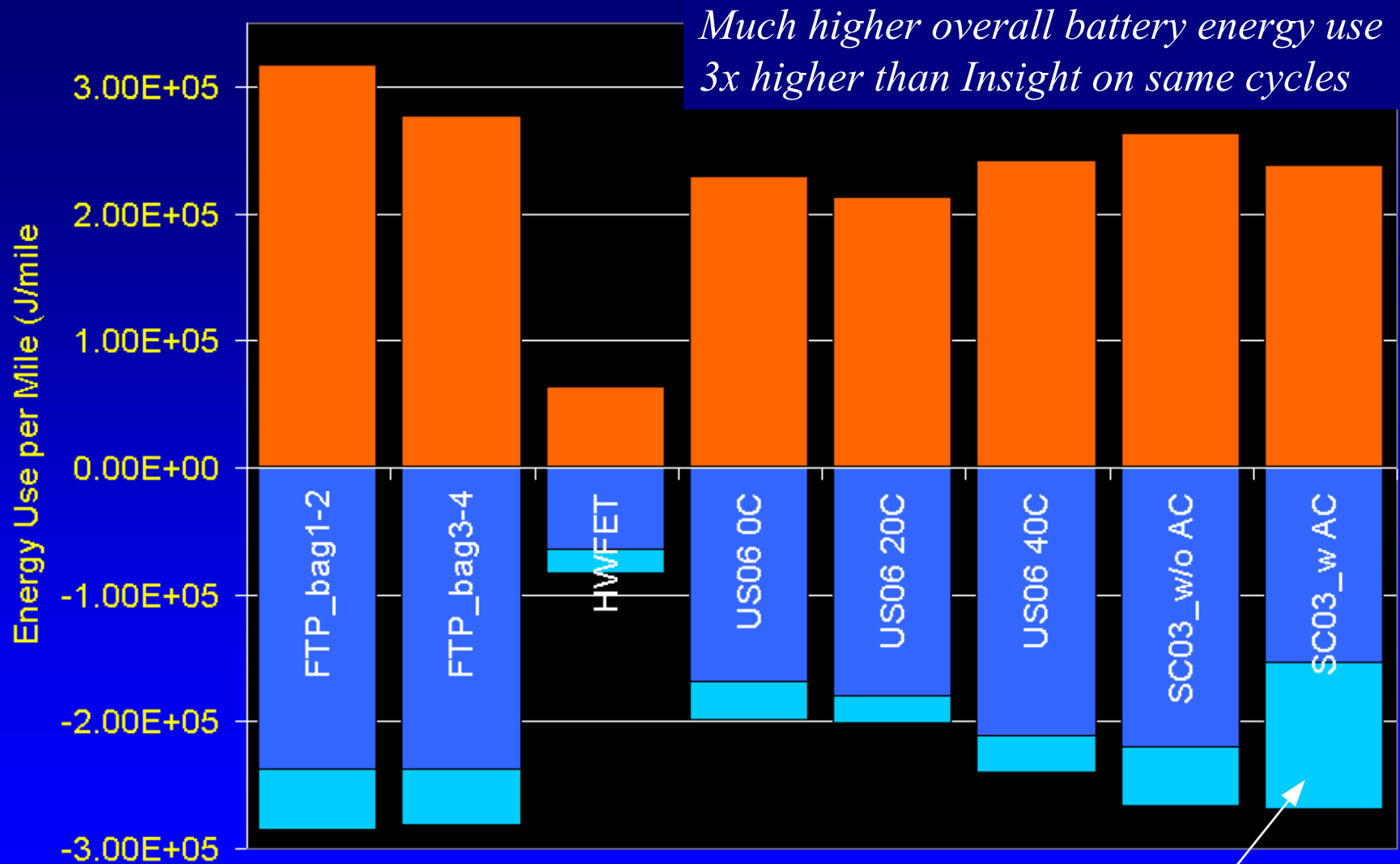




# Insight - Battery Pack Energy Usage



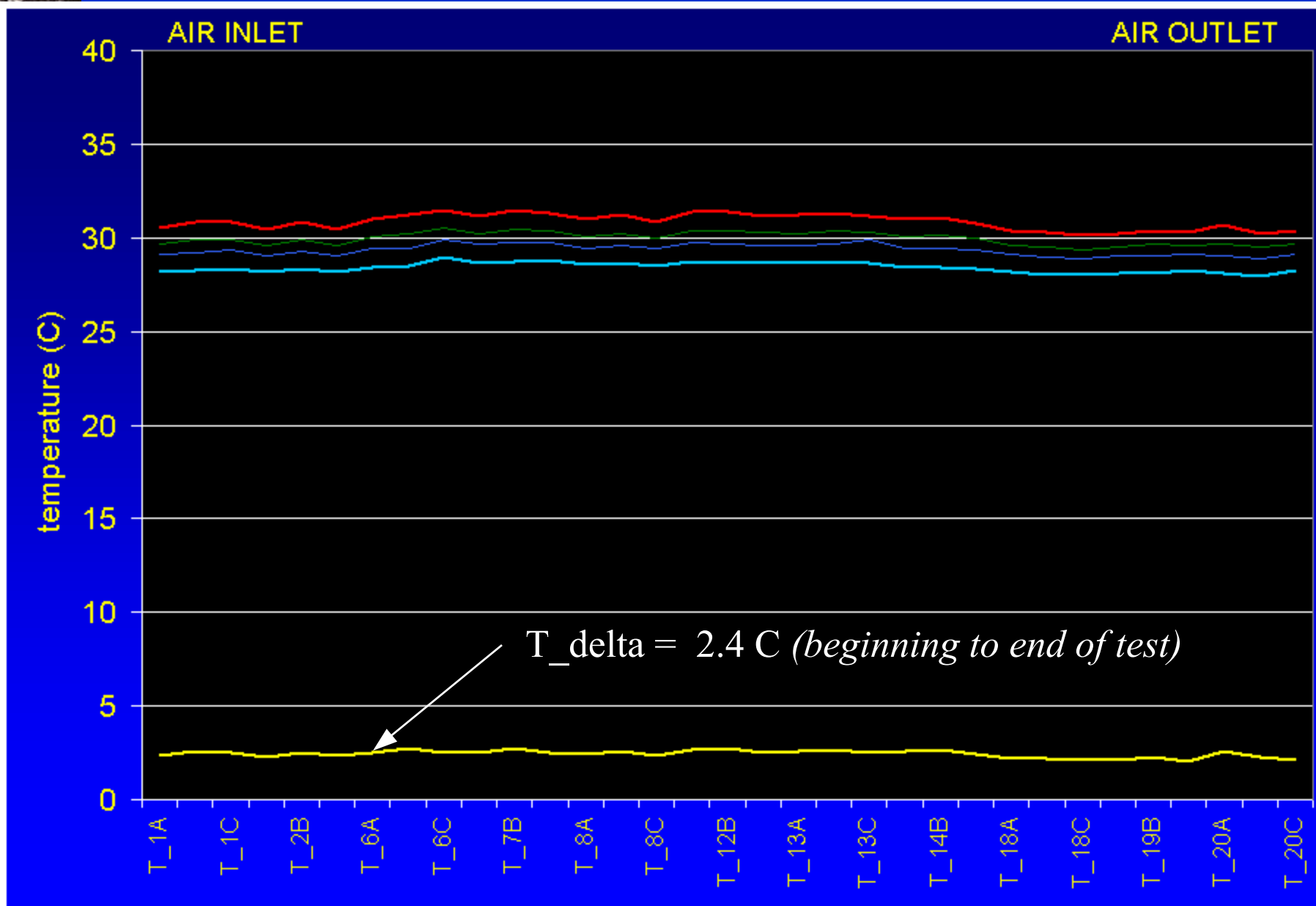
# Prius - Battery Pack Energy Usage



850 Watts average electrical accessory load with AC on

# Insight Test Data

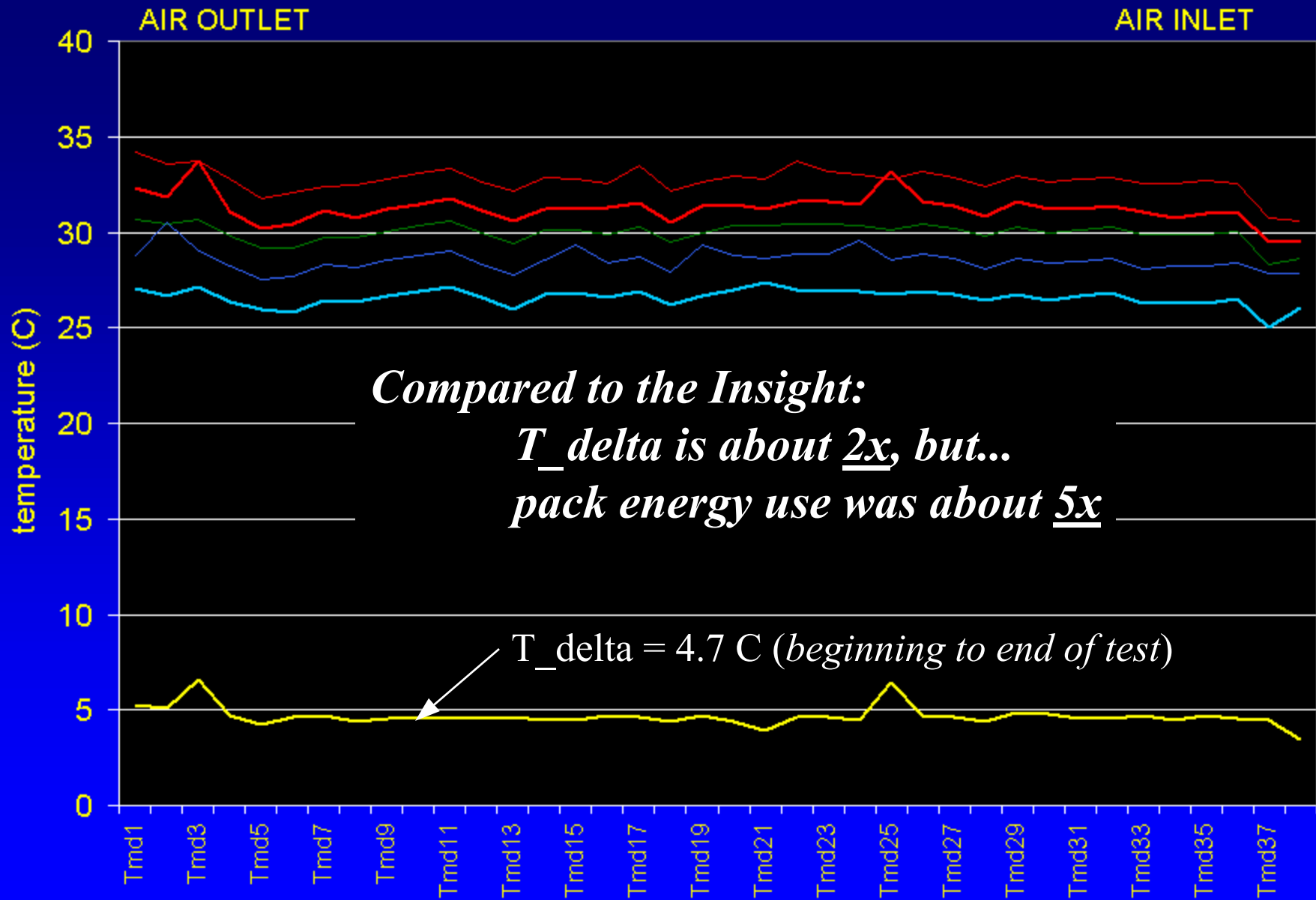
## Battery Temperature Effects - US FTP Cycle





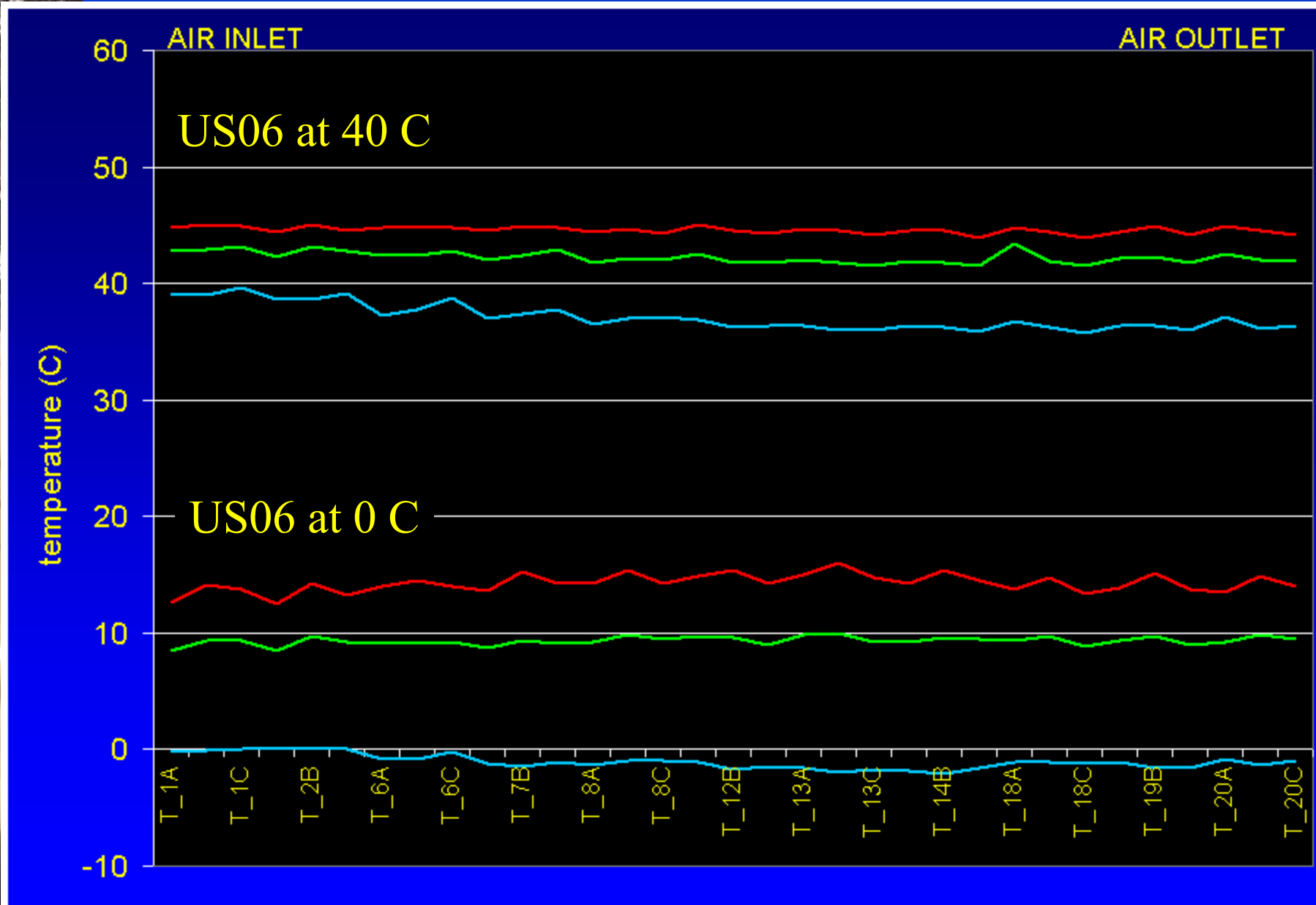
# Prius Test Data

## Battery Temperature Effects - US FTP Cycle



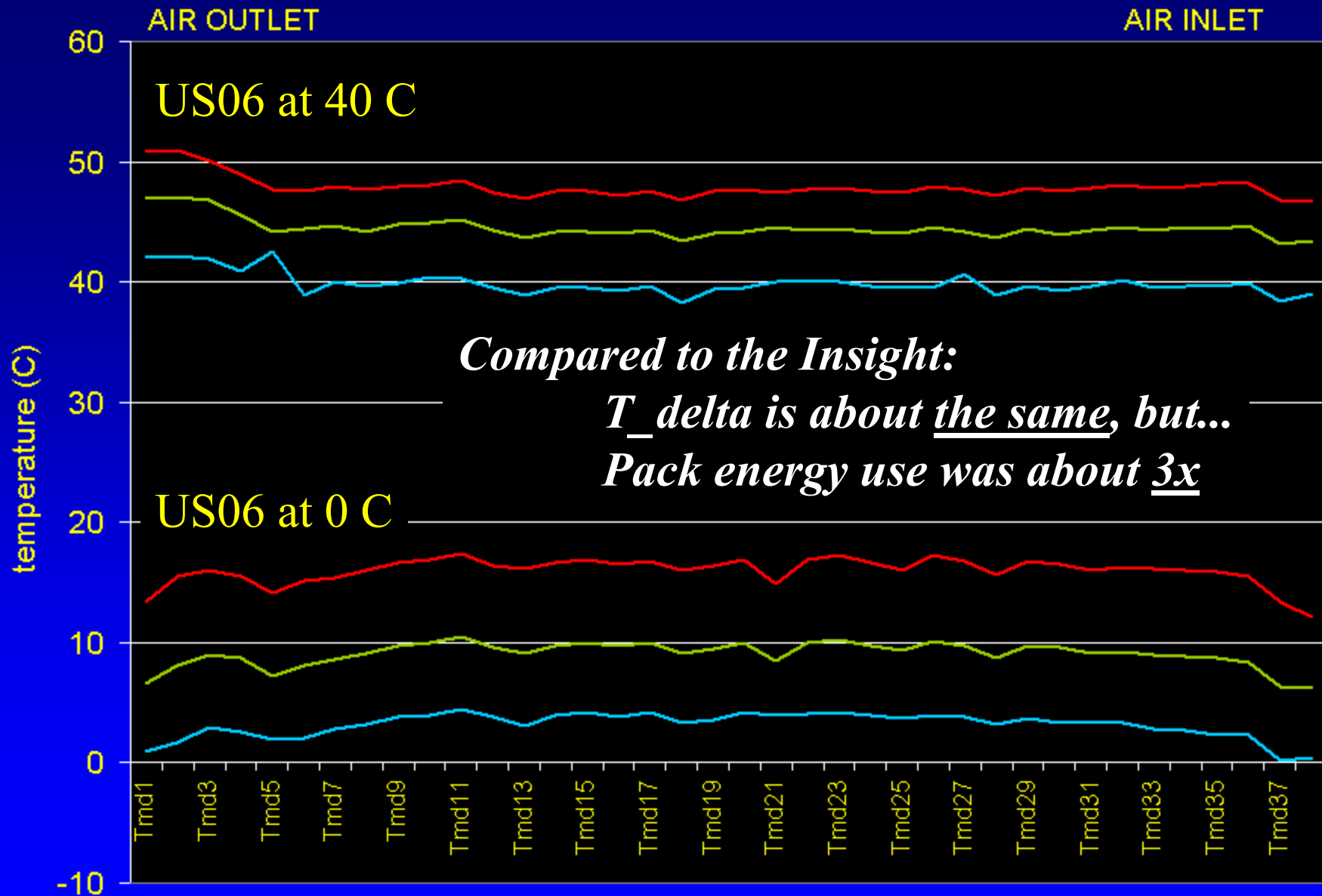
# Insight Test Data

## Battery Temperature Effects - US06 Cycle



# Prius - Test Data

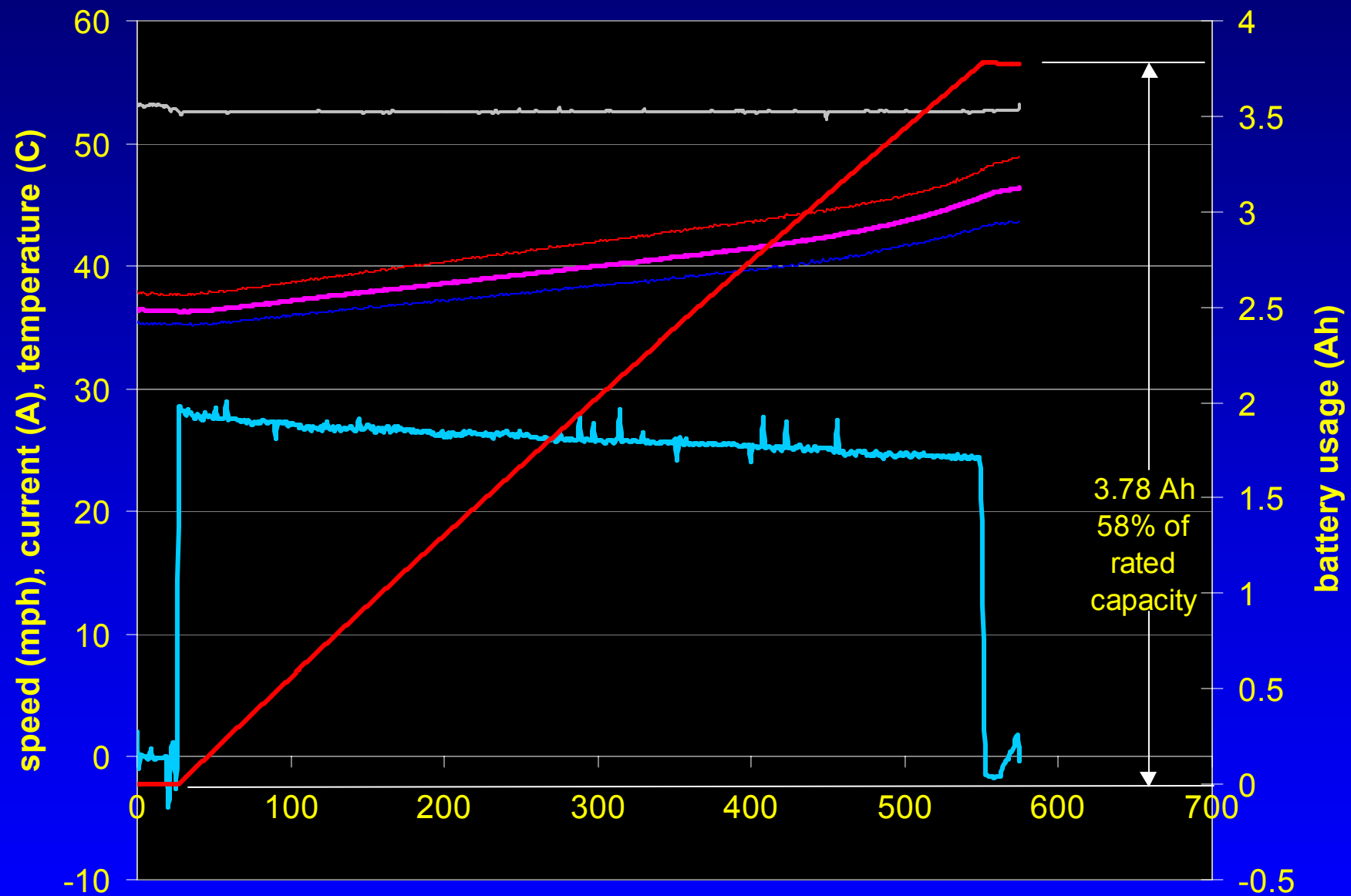
## Battery Temperature Effects - US06 Cycle





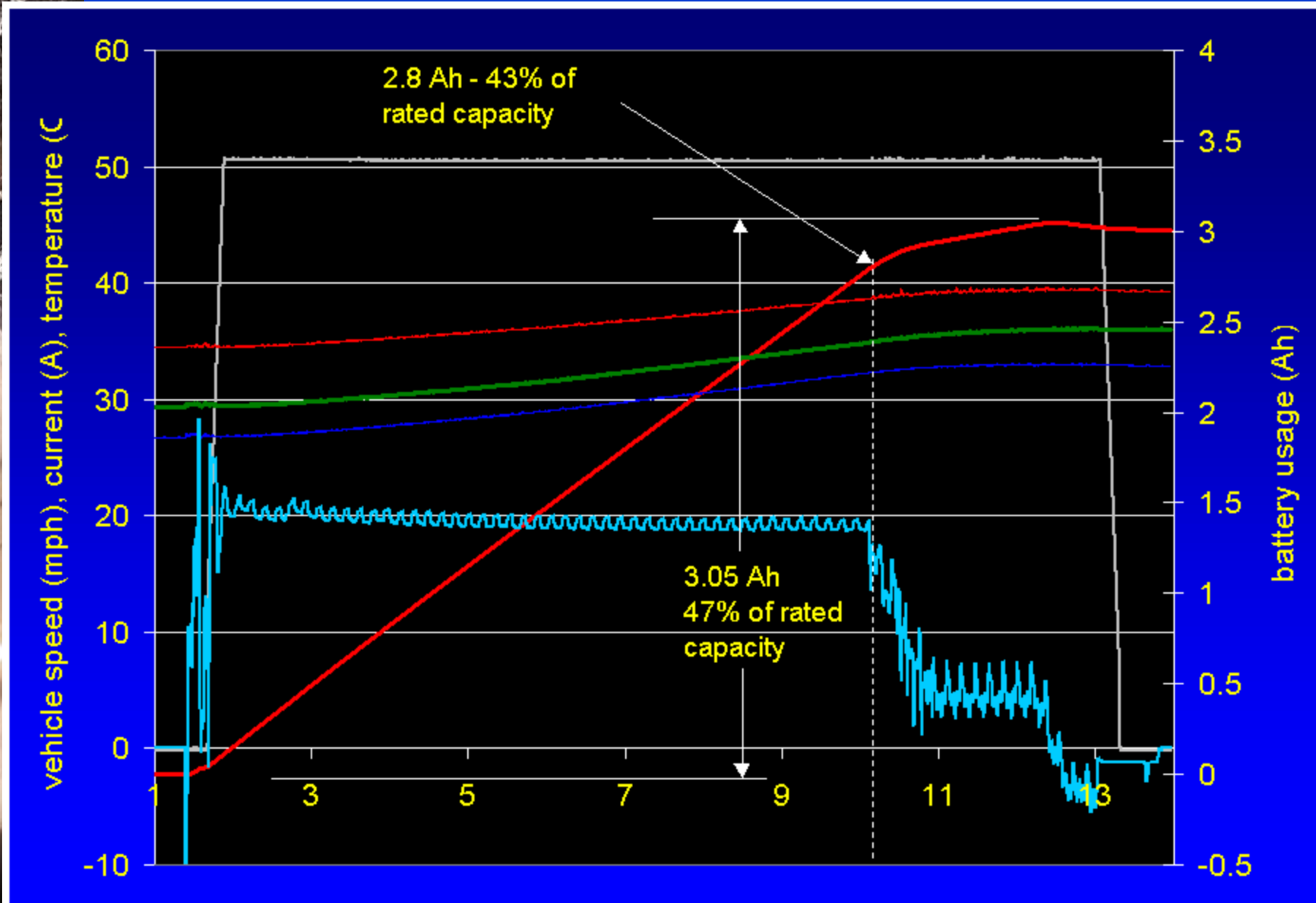
# Insight Test Data - Charge Cycle

*Useful Battery Capacity - 60% of Rated 6.5 Ah*



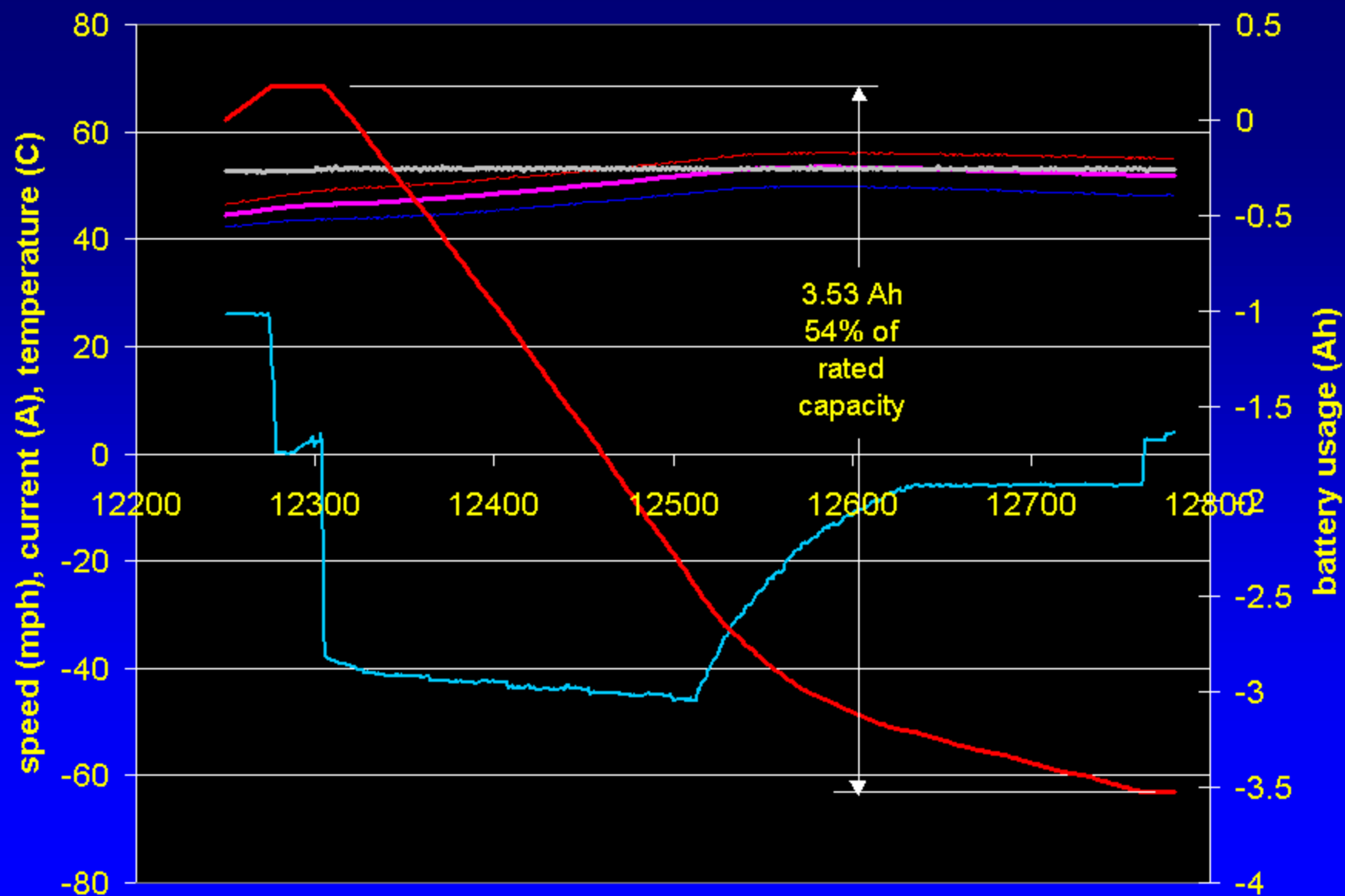
# Prius Test Data - Charge Cycle

Useful Battery Capacity - 40% of Rated 6.5 Ah (40% to 80% SOC)



# Insight Test Data - Discharge Cycle

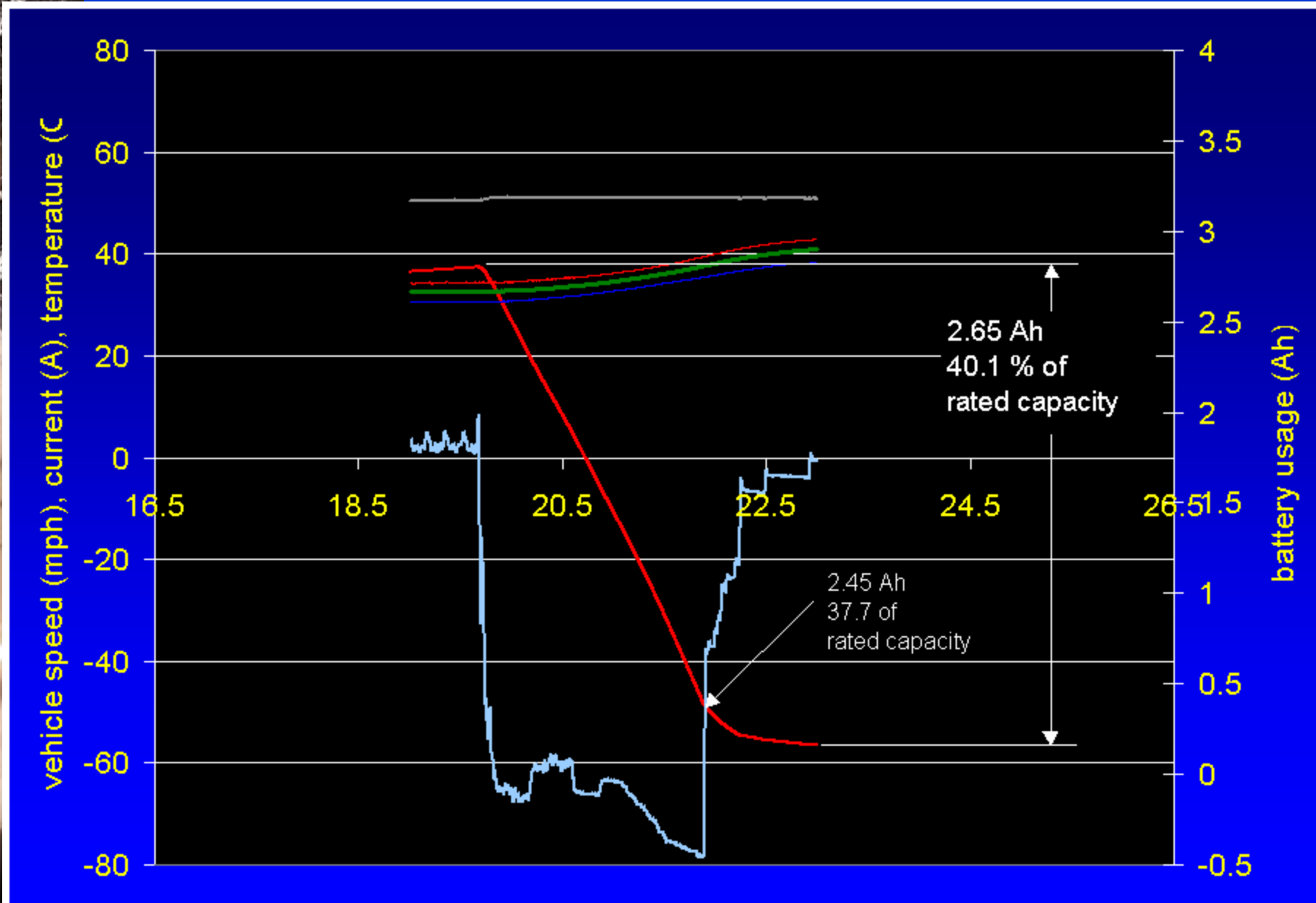
*Useful Battery Capacity - 60% of Rated 6.5 Ah*





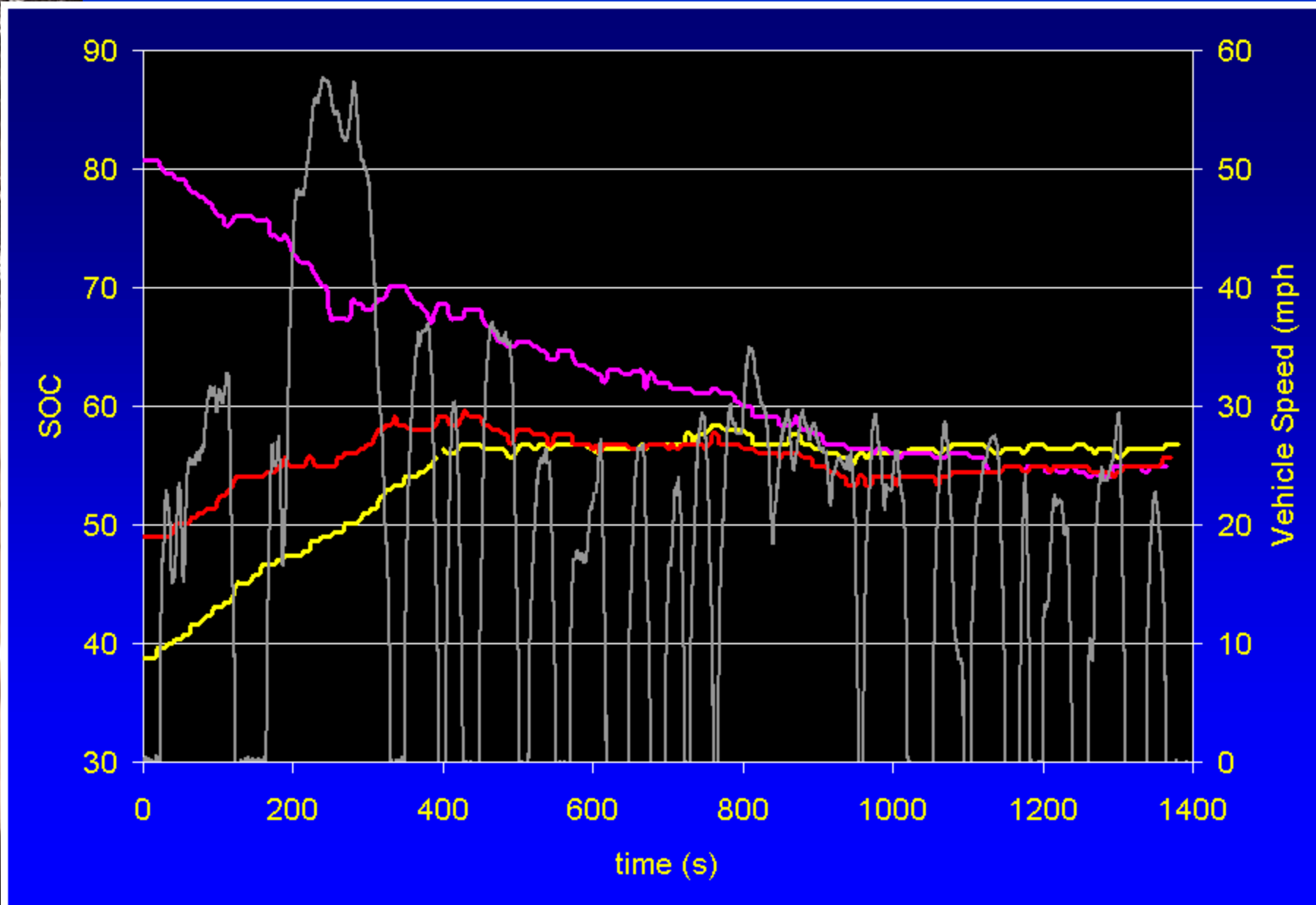
# Prius Test Data - Discharge Cycle

*Useful Battery Capacity - 40% of Rated 6.5 Ah (40% to 80% SOC)*



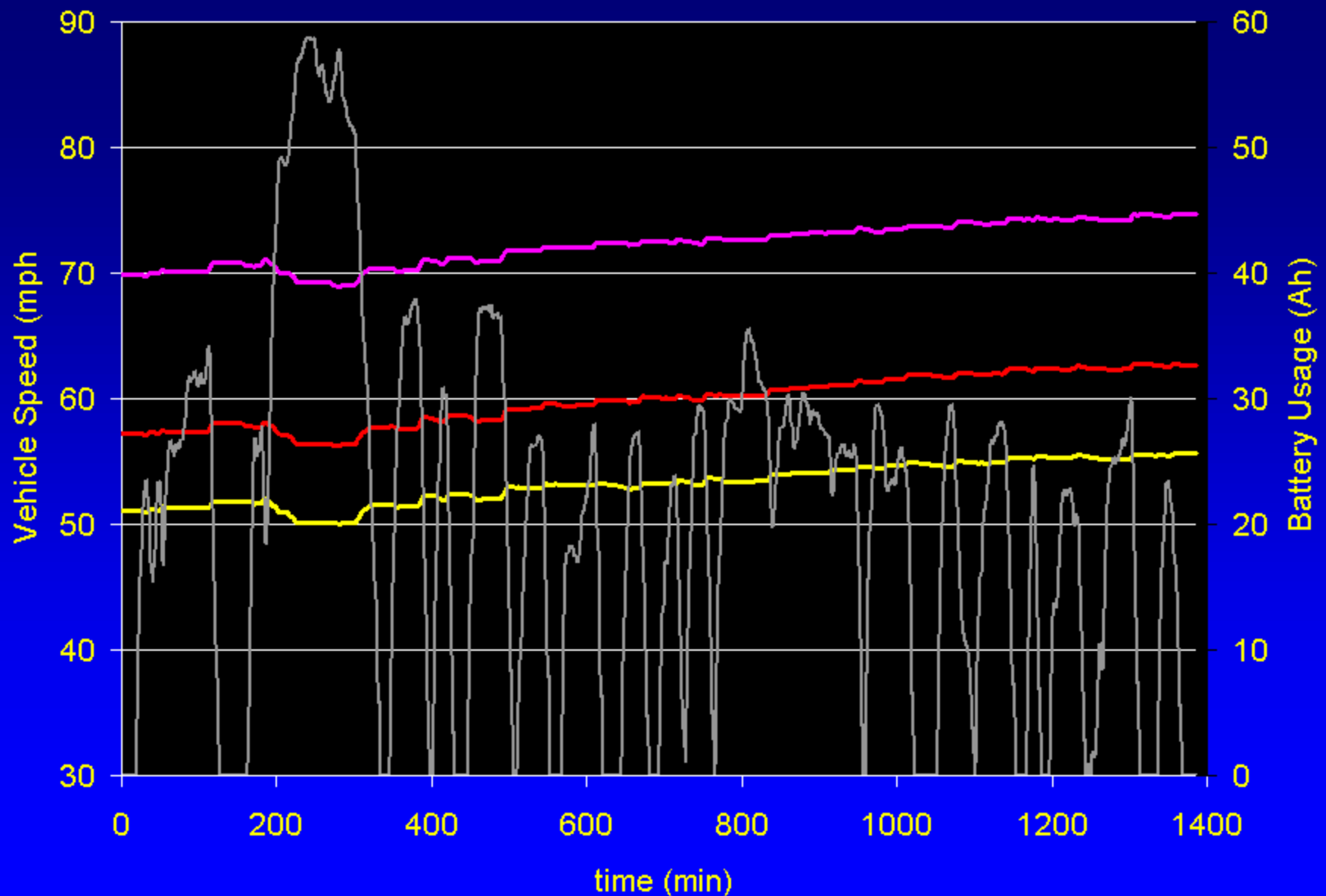
# Prius SOC Control on FTP cycle

*Final SOC ~ 56% with various initial SOC's (40% to 80%)*



# Insight SOC Control on FTP cycle

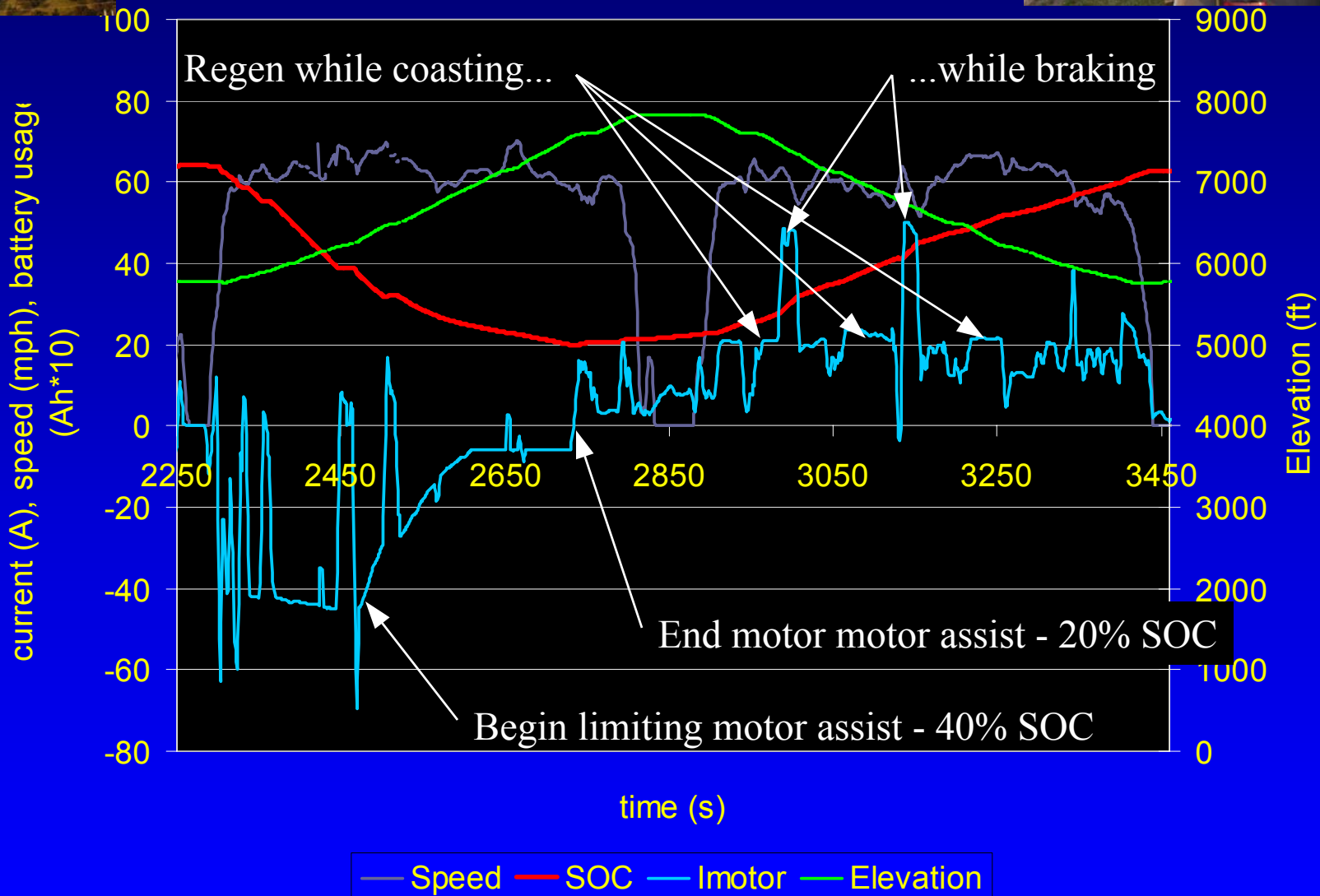
*SOC Profile - very similar behavior despite varying initial SOC*







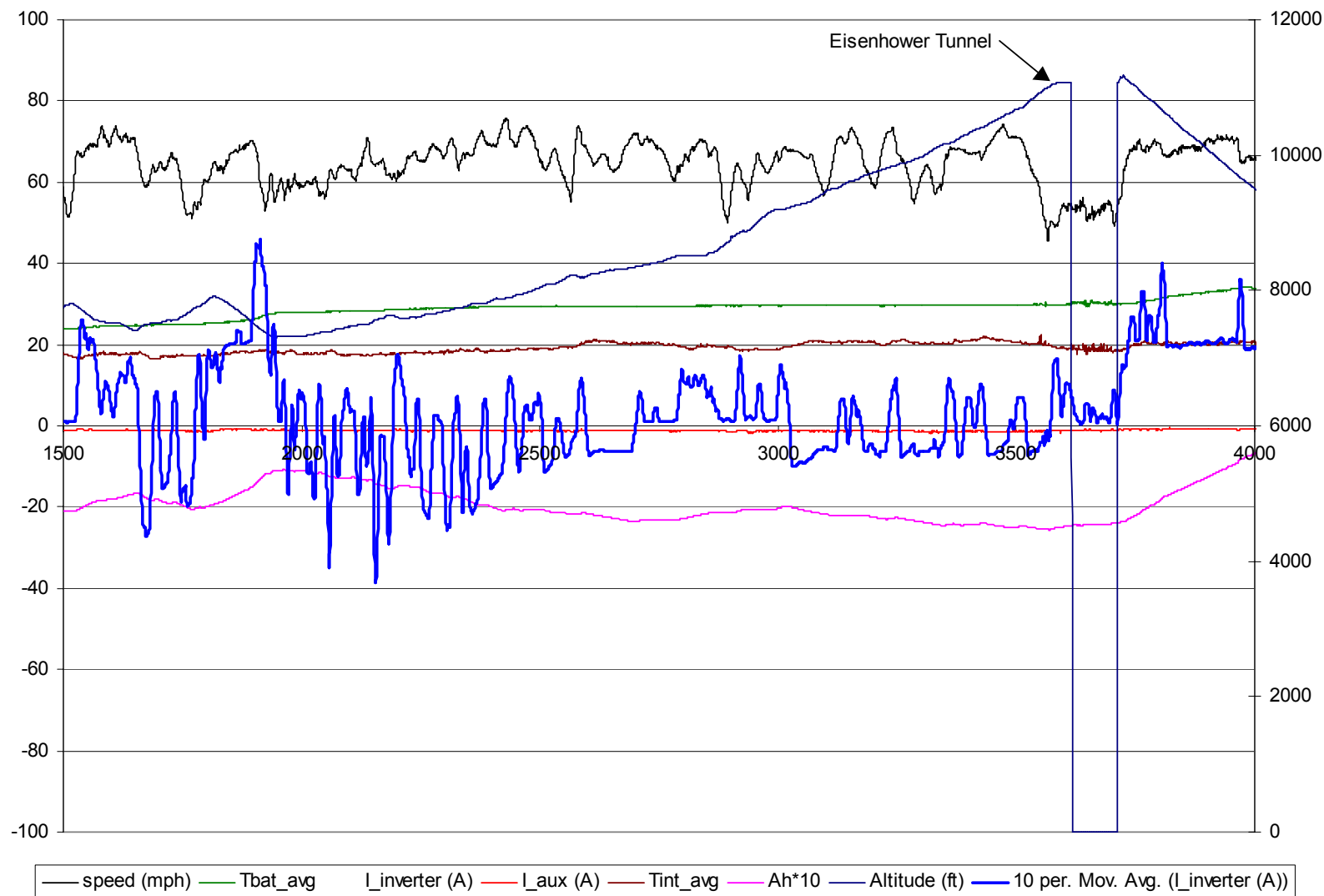
# Insight Test Data *On Road Driving*





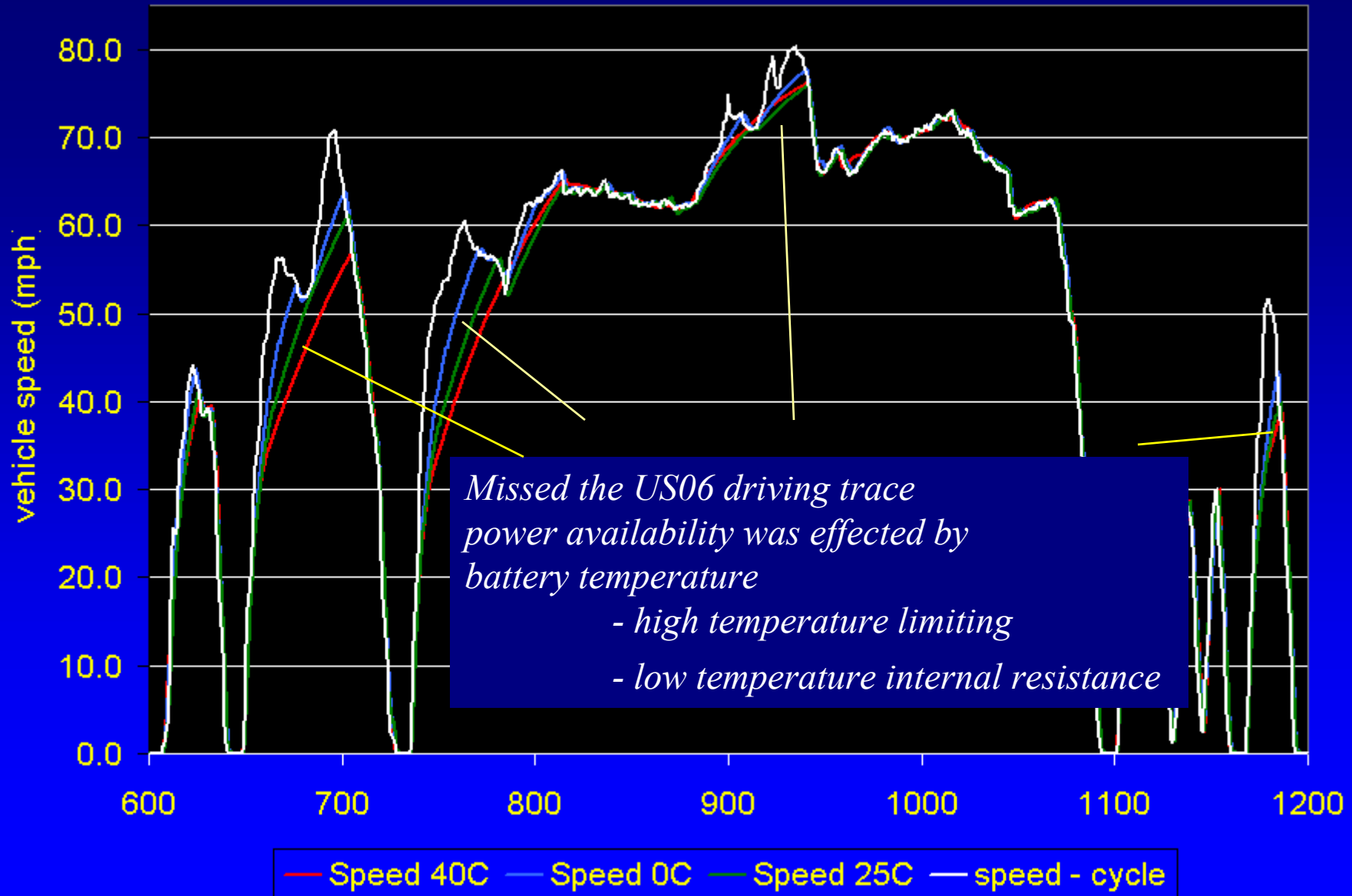
# Insight Test Data

## On Road Driving - NREL to VAIL



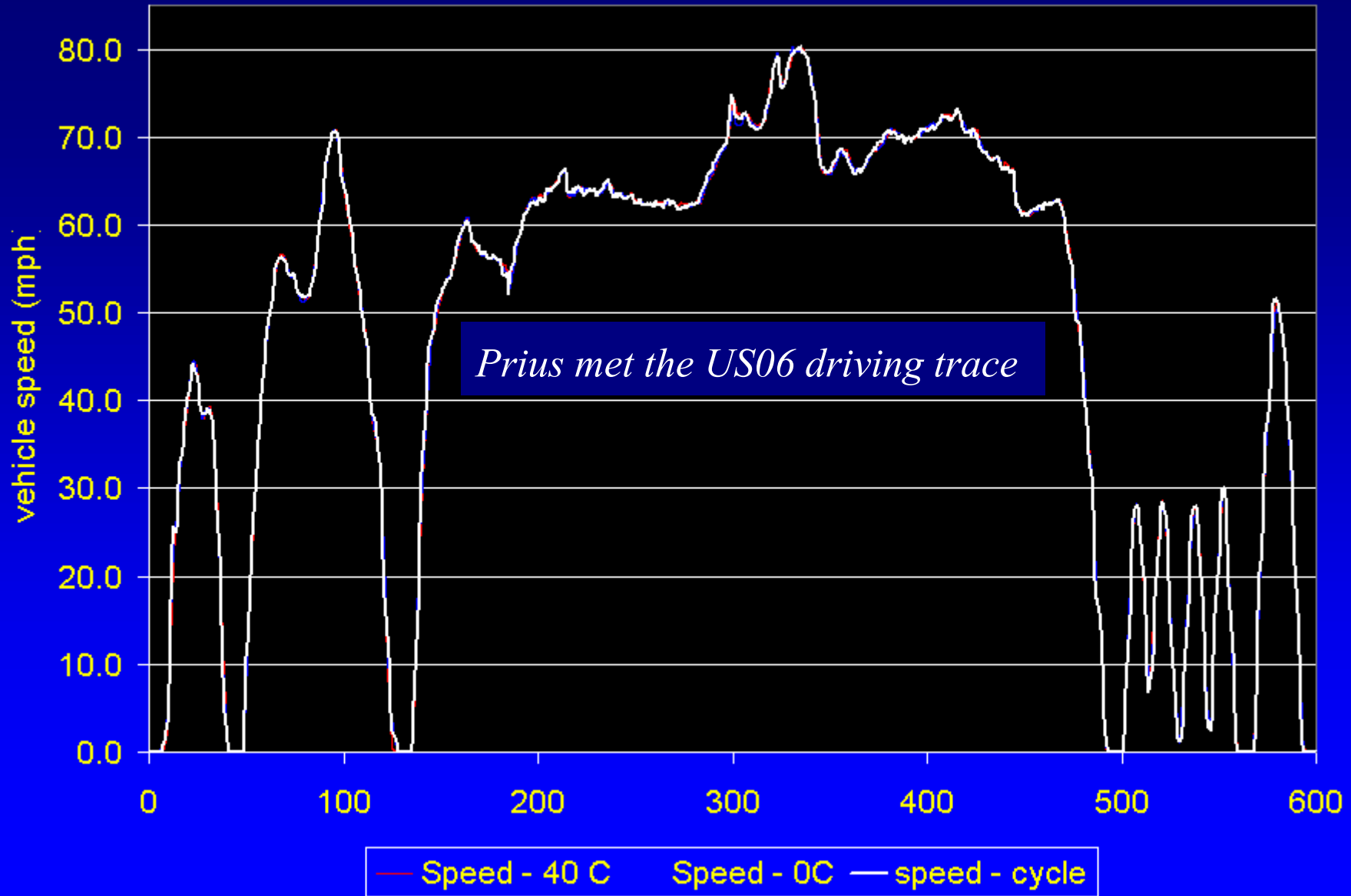
# Insight Test Data - Aggressive Driving (US06)

US06 (second cycle - 0 C blue, 20 C green, 40 C red)



# Prius Test Data - Aggressive Driving (US06)

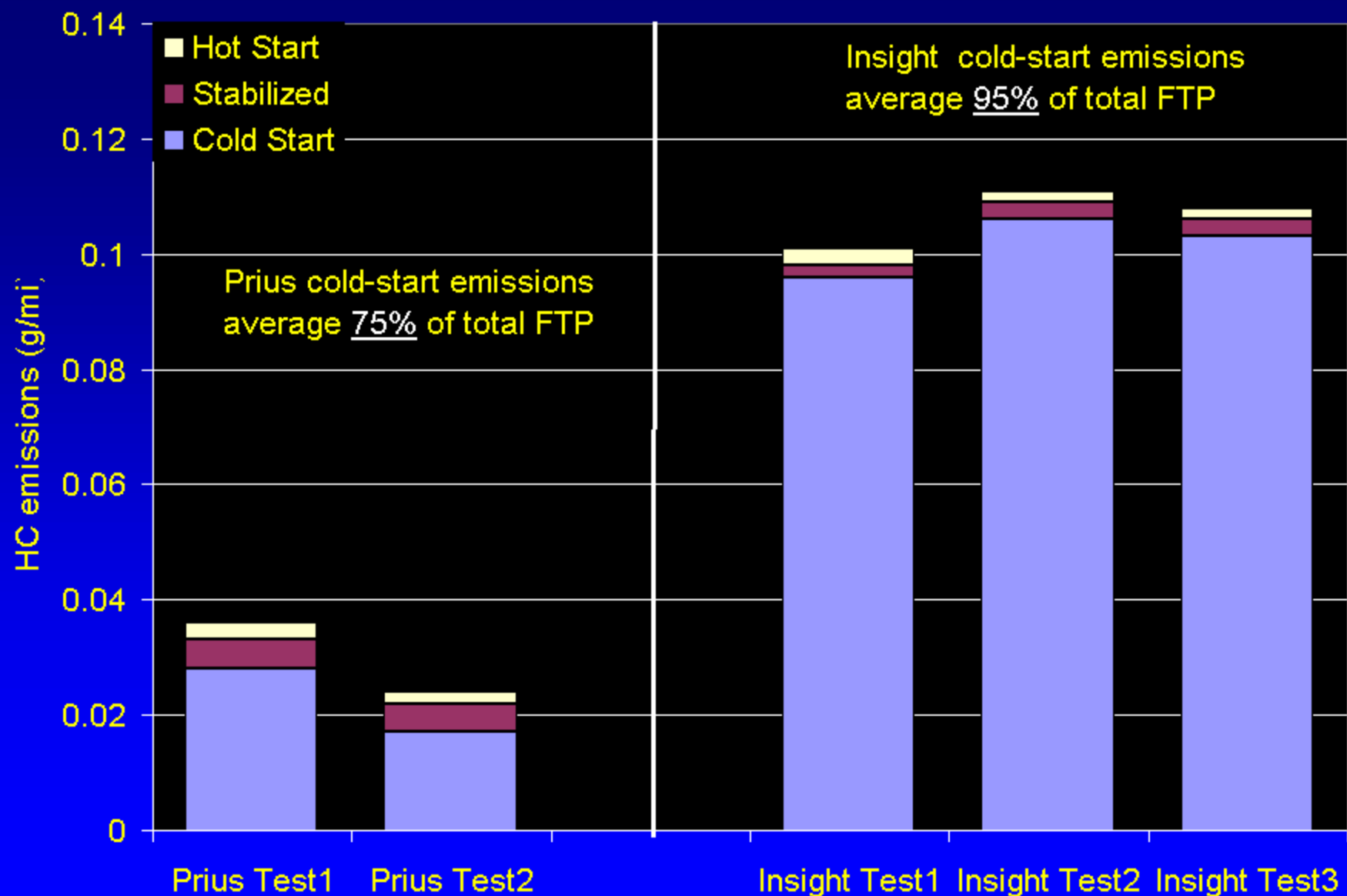
US06 (second cycle - 0 C blue, 20 C green, 40 C red)



# Emissions Control Strategies

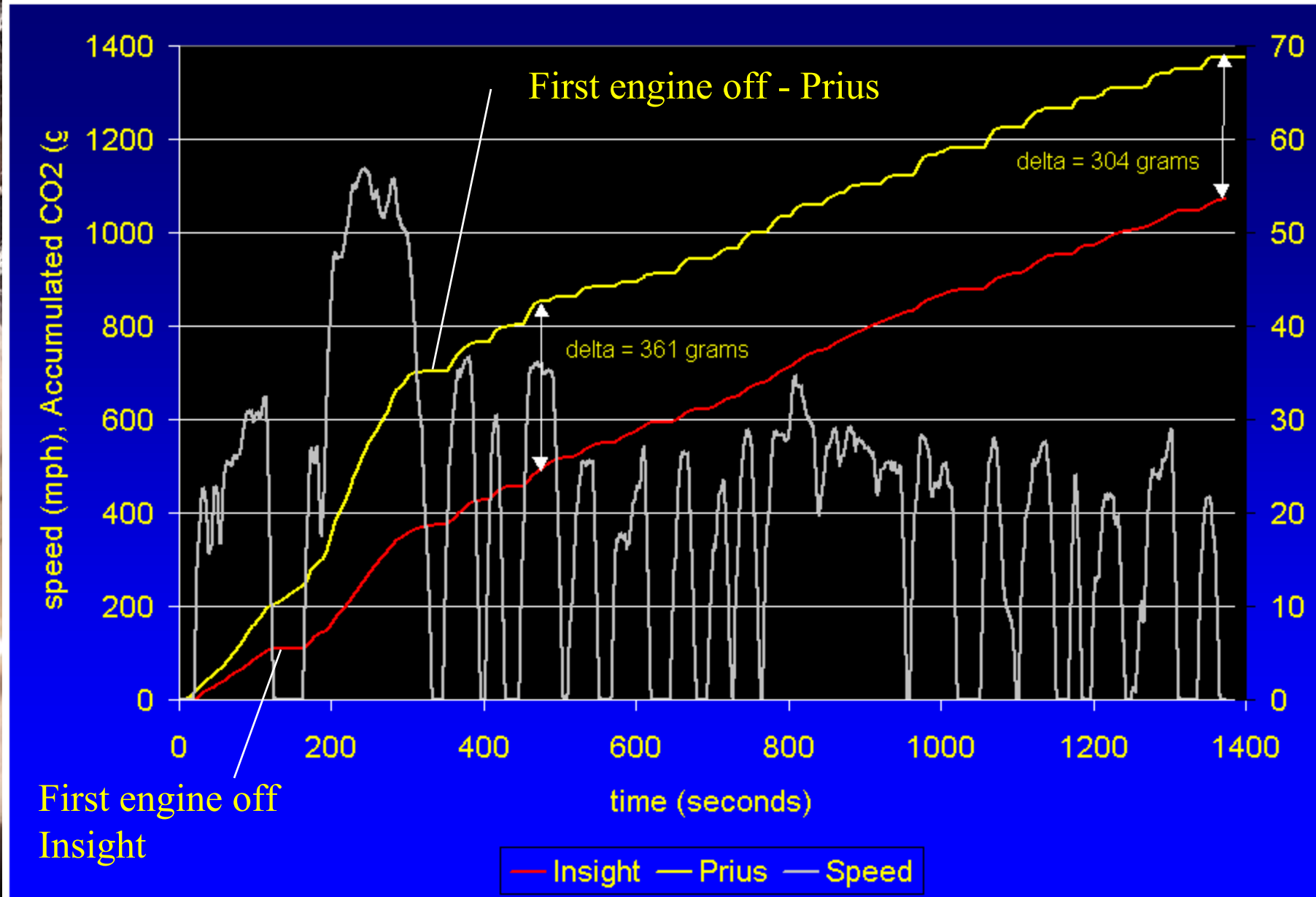
*Prius - HC Adsorber*

*Insight - Lean NOx Adsorber*

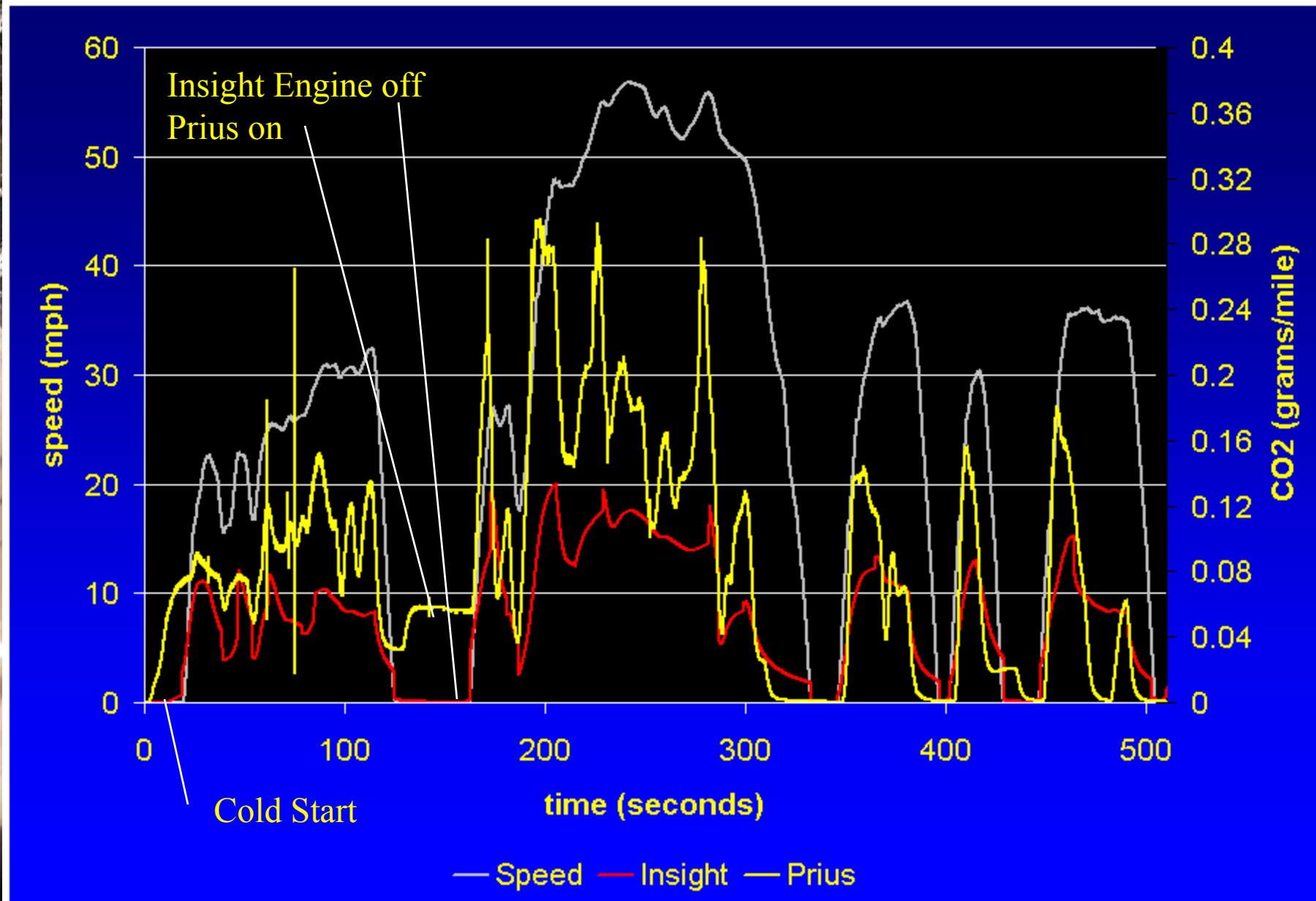




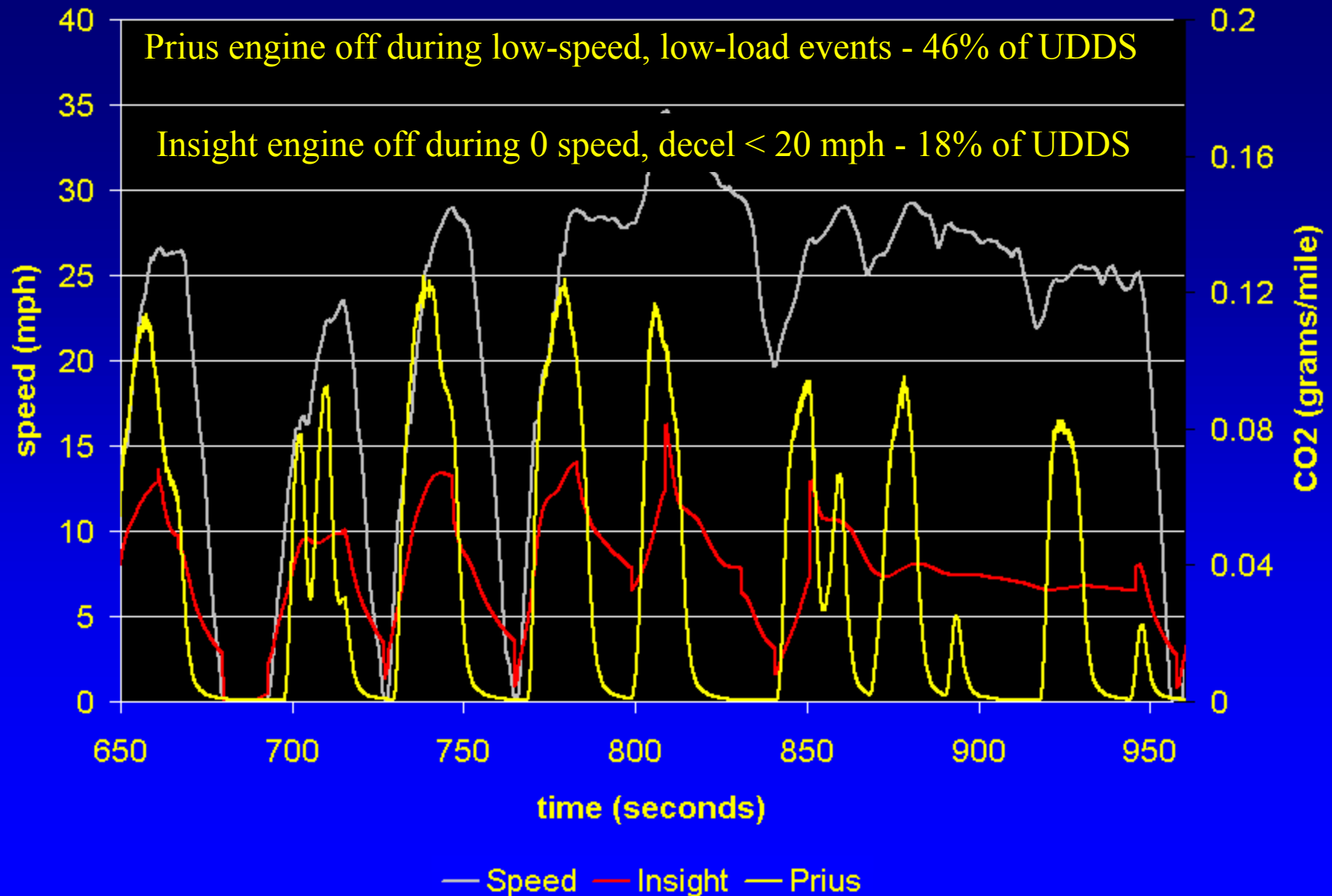
# Accumulated CO2 Emissions on the FTP Cycle: Insight & Prius



# CO2 Emissions on the FTP Cycle: Insight & Prius

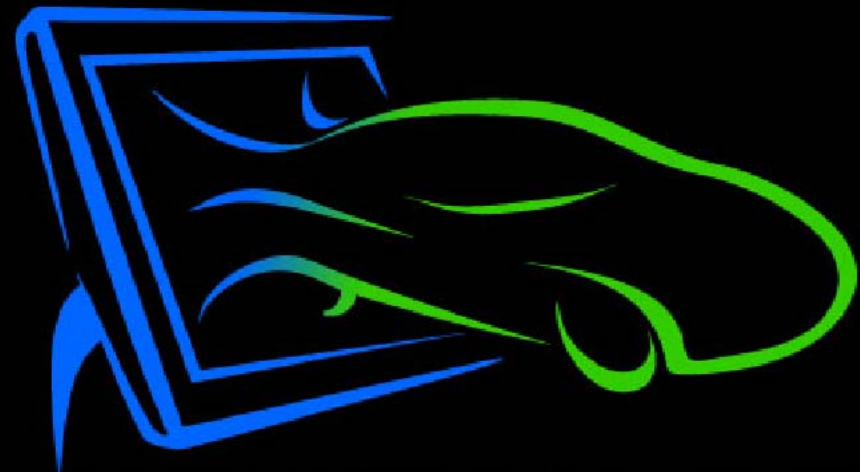


# CO2 Emissions on the FTP Cycle: Insight & Prius





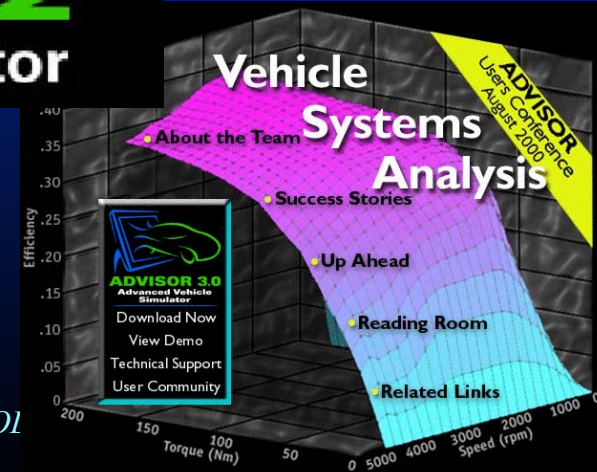
*... including an updated  
version of the Honda  
Insight model*



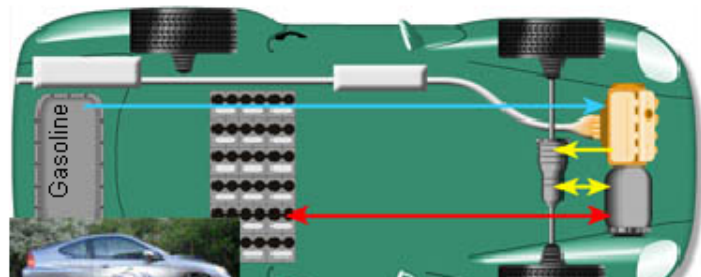
**ADVISOR 3.2**  
Advanced Vehicle Simulator



*NREL, CENTER FOR TRANSPORTATION TECHNOLOGY*



## Vehicle Input

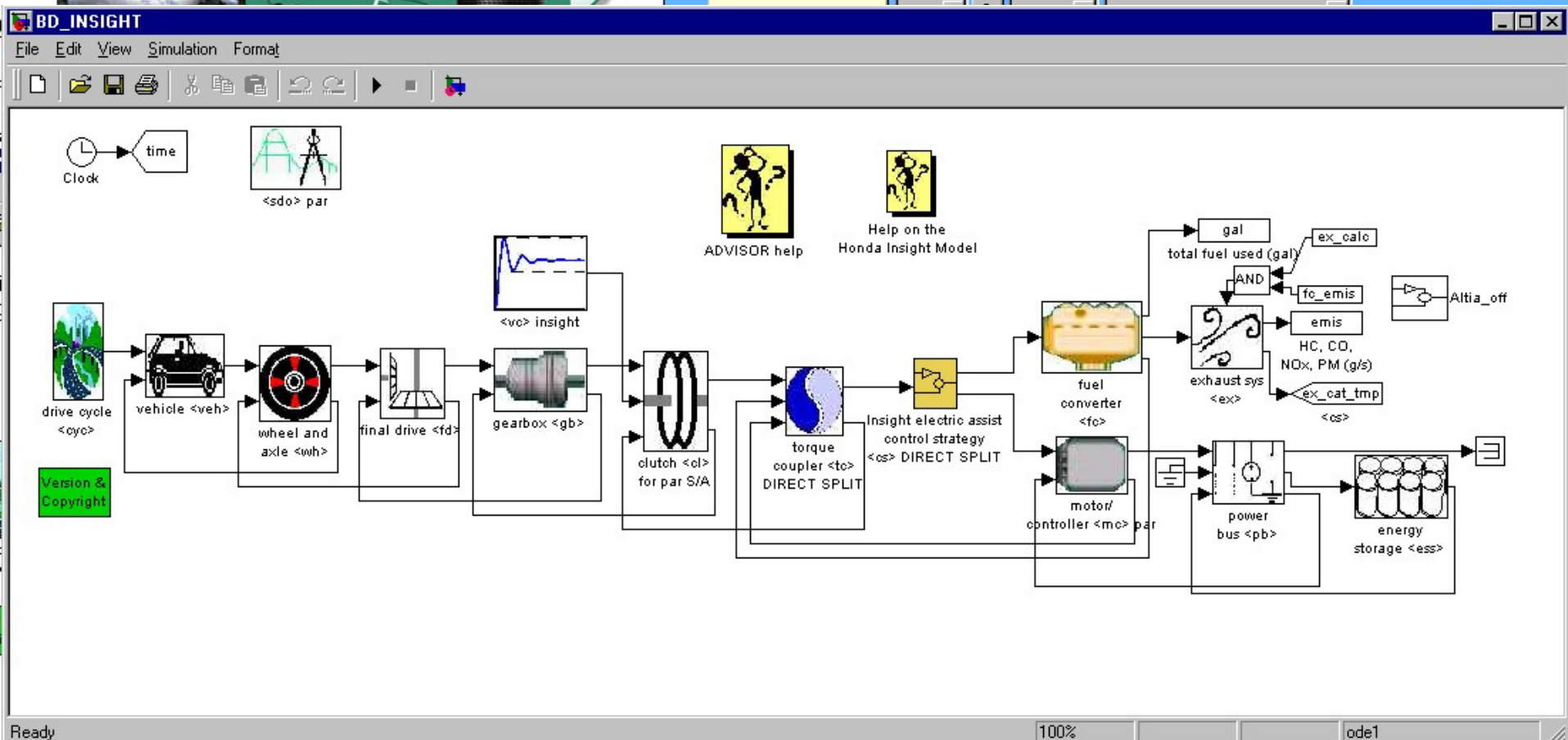


Load File: INSIGHT\_defaults\_in

Drivetrain Config: insight

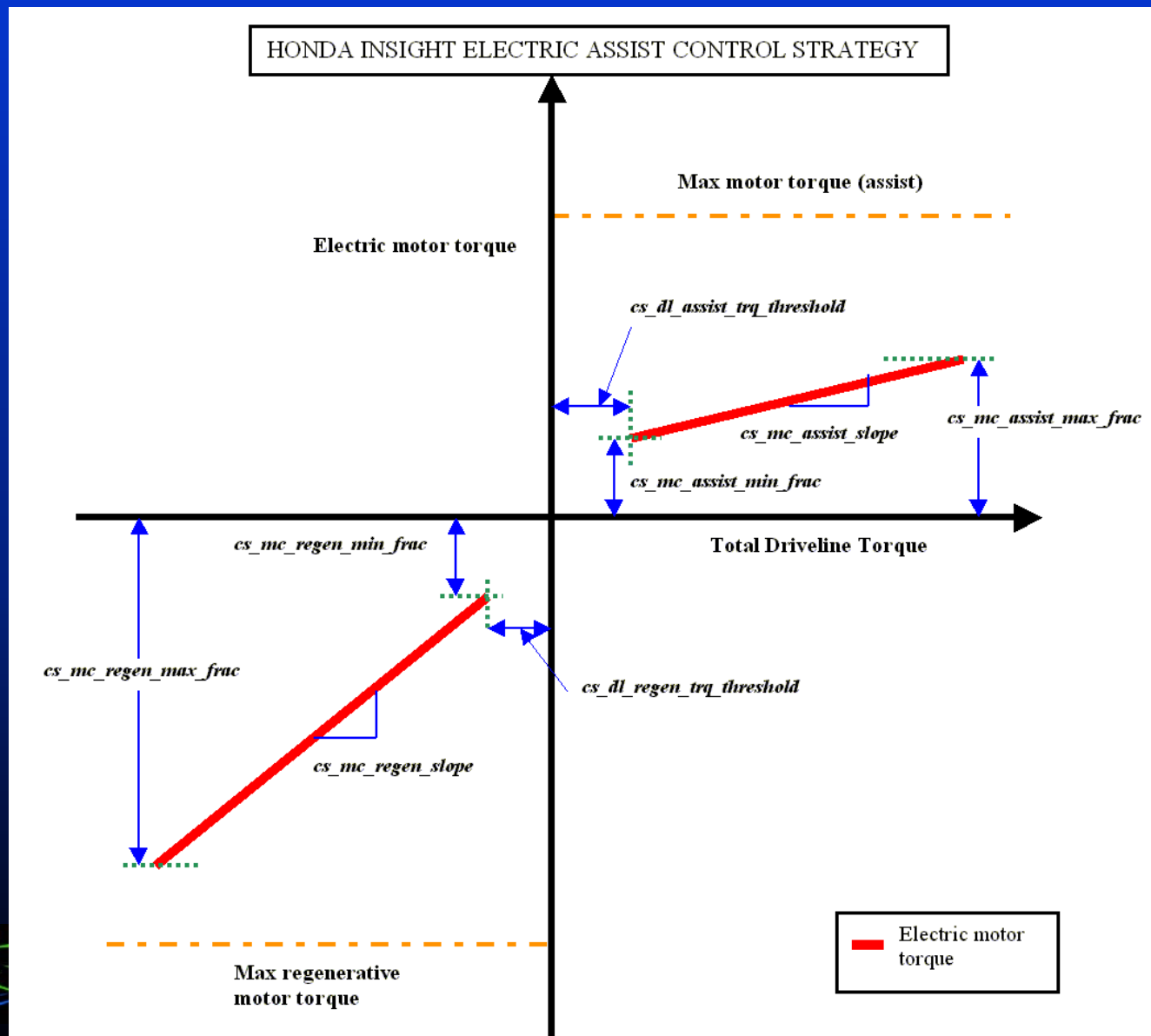
	version	type		max pwr (kW)	peak eff	mass (kg)
<input checked="" type="checkbox"/> Vehicle		?	VEH_INSIGHT			520
<input checked="" type="checkbox"/> Fuel Converter	v01	?	FC_INSIGHT_draft	50	0.34	129
<input checked="" type="checkbox"/> Exhaust Aftertreat		?	EX_SI_CC	#of mod	V nom	5
<input checked="" type="checkbox"/> Energy Storage	v01	?	ESS_INSIGHT_draft	20	155	20
Energy Storage 2		?	ess 2 options			
<input checked="" type="checkbox"/> Motor		?	MC_INSIGHT_draft	10	0.96	60

Auto-Size



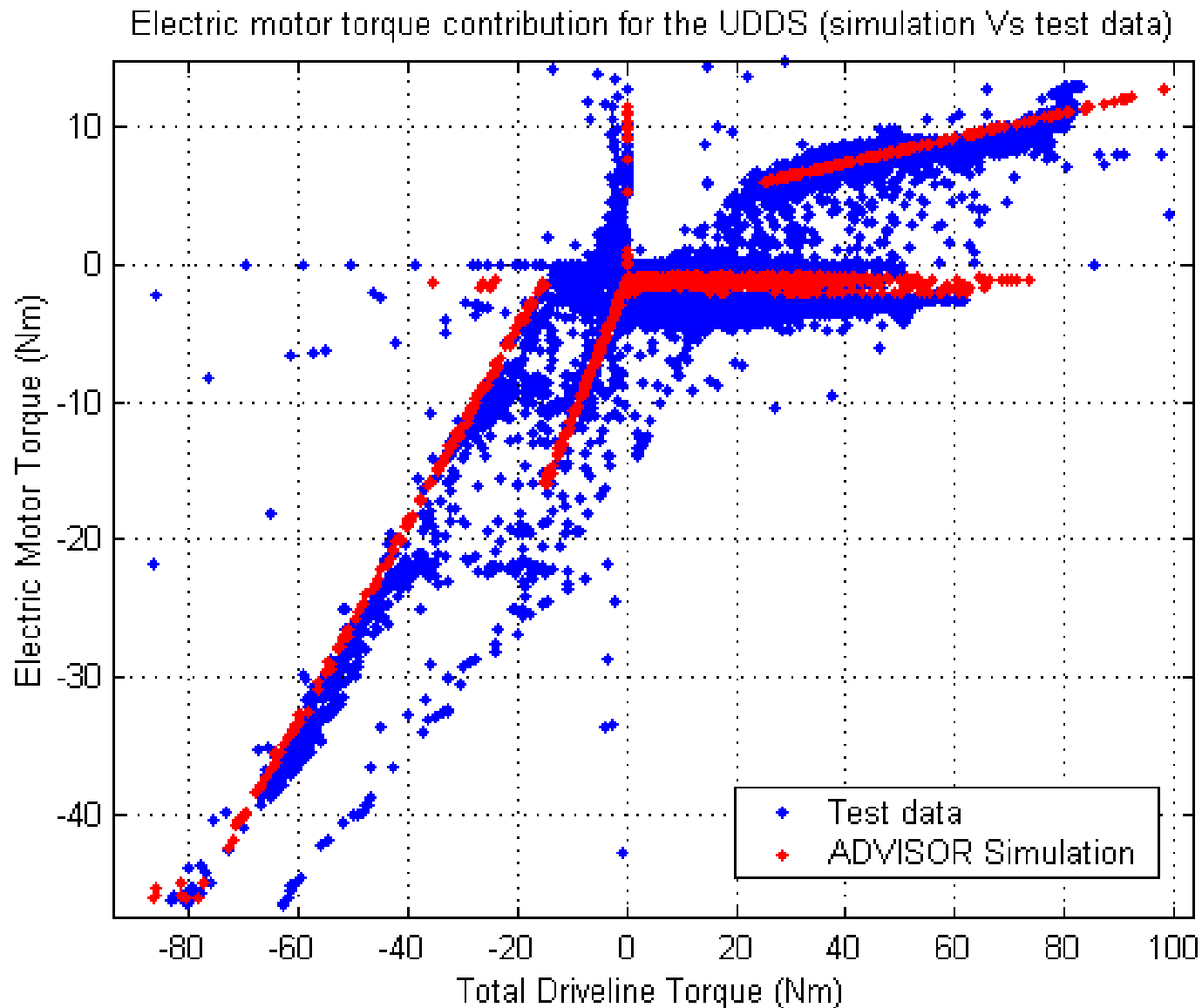


# Parametric Model of Insight Torque Split



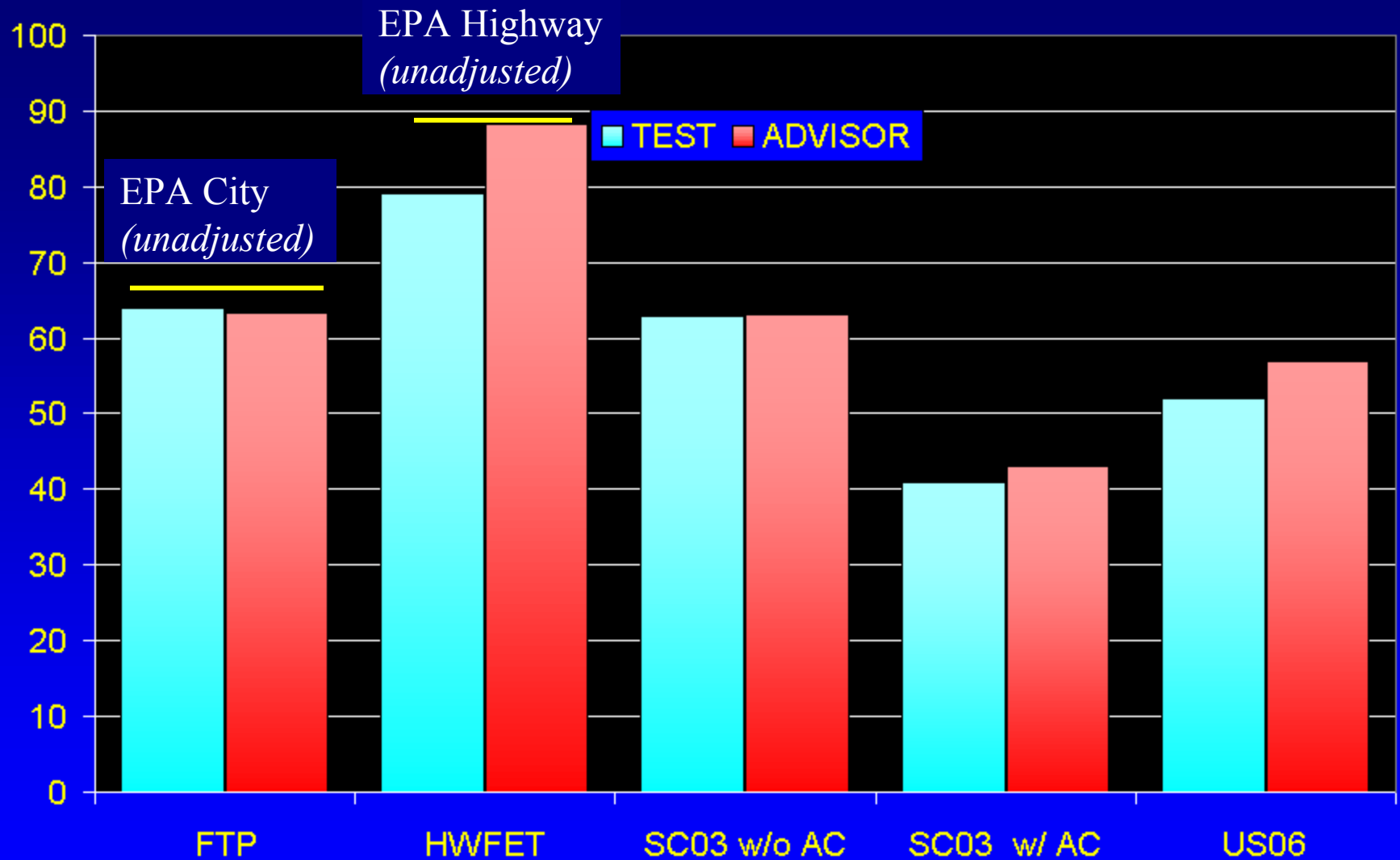
# Test Data vs ADVISOR Simulation

## *Motor Torque vs. Driveline Torque Request*



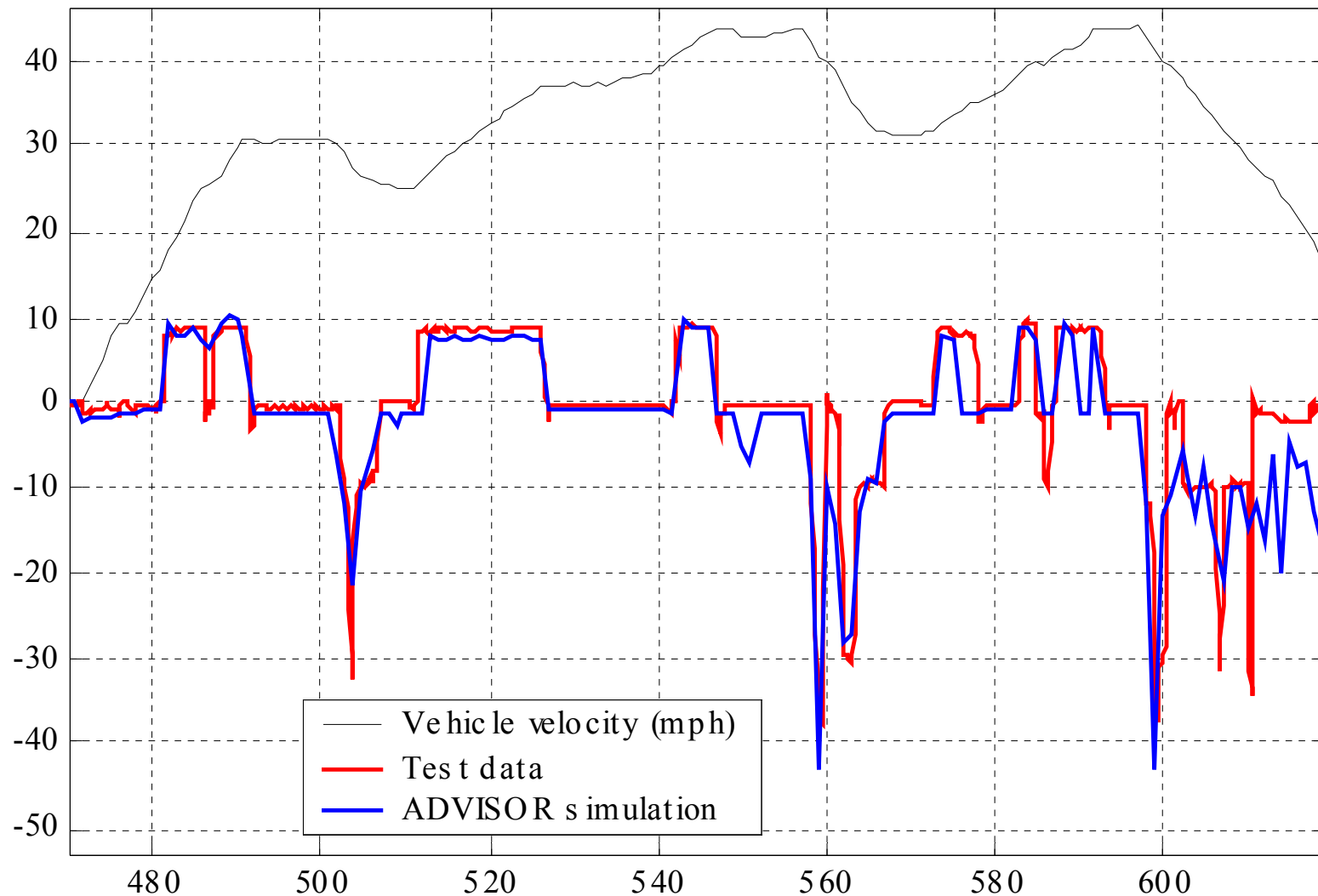
# Fuel Economy Comparison

## *Insight Test Data vs. ADVISOR*



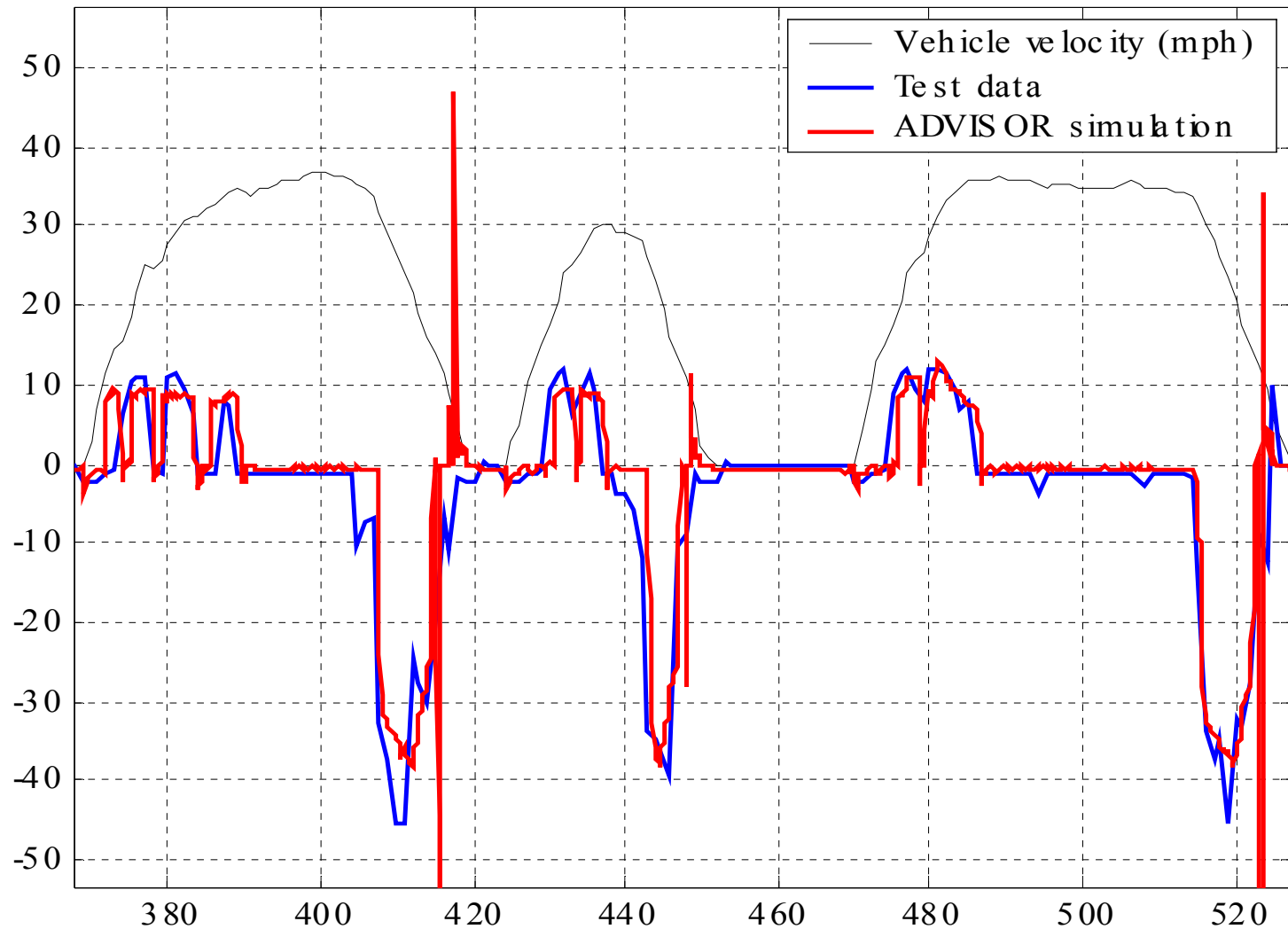
# Comparison of ADVISOR Simulation to Test Data

## *Motor Torque on Japanese 1015 Drive Cycle*



# Comparison of ADVISOR Simulation to Test Data

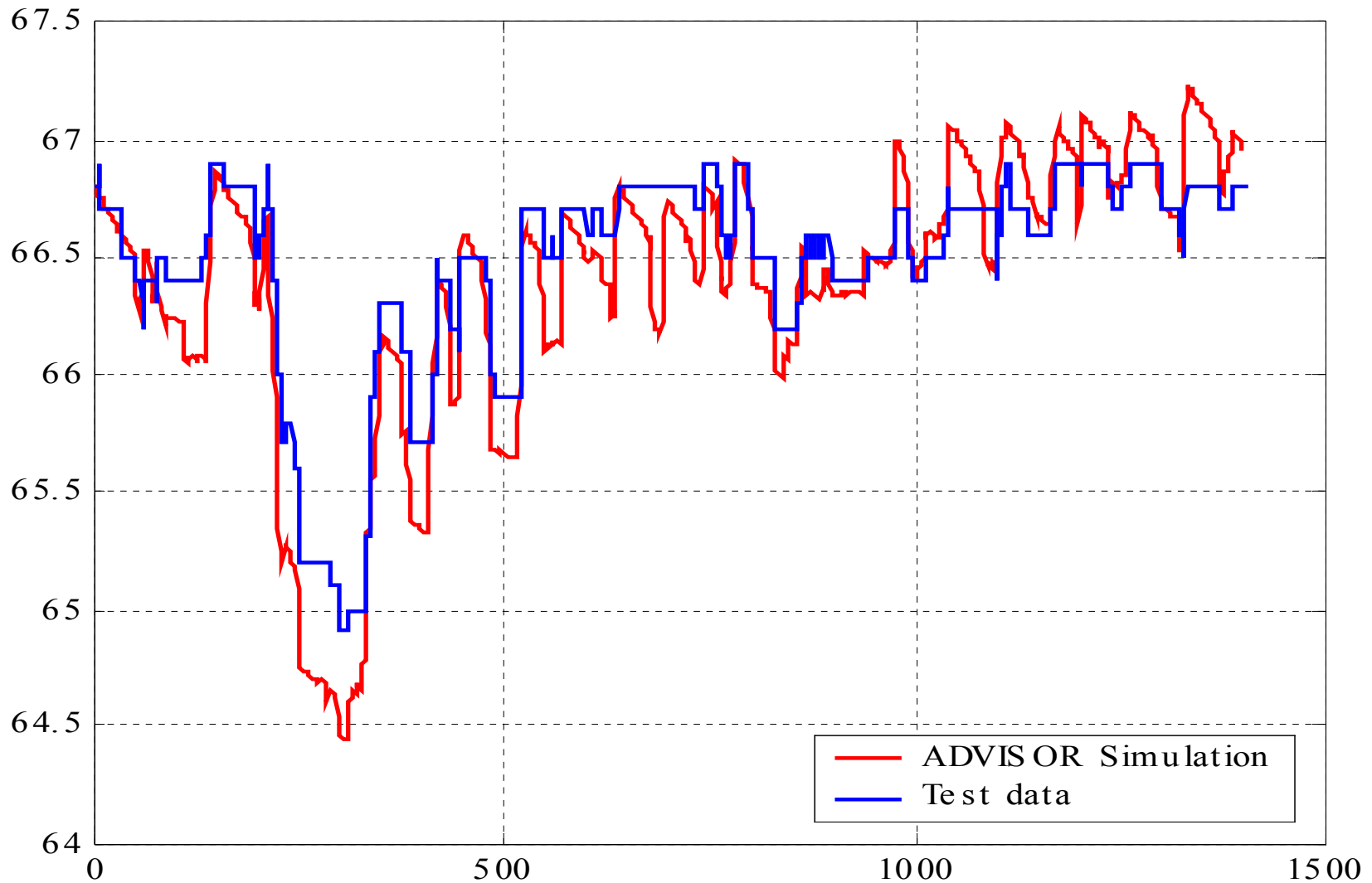
## Motor Torque on FTP Drive Cycle





# Comparison of ADVISOR Simulation to Test Data

## *SOC on FTP Drive Cycle*



# Status and Conclusions

Insight testing is complete an updated model now available in ADVISOR 3.2 release

1st round of Prius testing complete

Prius and Insight showed 30% - 33% drop in fuel economy with Air Conditioning

- Insight showed increased NO<sub>x</sub>
- Prius showed increase HC and CO

Prius exhibited more robust battery thermal management design

- both vehicles use forced cabin air
- both system are adequate under moderate conditions

Battery Pack Control Limits

- Insight - 60% of 6.5 Ah (144 V)
- Prius - 40% of 6.5 Ah (280 V)



# Conclusions

## SOC Control

- Insight does not appear to have a target SOC
- Prius rapidly brings SOC to ~56%

Insight failed to meet US06 aggressive driving trace - problem was exacerbated by:

- low temperature battery internal resistance
- high temperature power limiting for temperature control

Prius met the US06 trace under all test conditions

Prius HC trap effective in reducing cold start HC's

Prius exhibits significant engine-off operation, which appears to limit fuel use.

Latest ADVISOR model of Insight accurately predicts overall fuel-use and component behavior



# Recent Publications...

*Battery Usage and Thermal Performance of the Toyota Prius and Honda Insight during Chassis Dynamometer Testing, 17<sup>th</sup> Annual Battery Conference on Applications and Advances, Long Beach, CA, January 2002*

*Benchmarking of OEM Hybrid Vehicles at NREL, NREL, August 2001*

*Test Results and Modeling of the Honda Insight Using ADVISOR, SAE 01FTT-69, August 2001*

*Thermal Evaluation of a Toyota Prius HEV Battery Pack, NREL, May 2001*

*Thermal Evaluation of the Honda Insight Battery Pack, IECEC2001-ET-07, August 2001*



NREL, CENTER FOR TRANSPORTATION TECHNOLOGIES AND SYSTEMS



# Acknowledgements

***DOE - Office of Advanced Automotive Technologies***  
***Bob Kost - Systems Analysis Team Leader***

**Battery Thermal Management Team at NREL**

**Environmental Testing Corporation - Aurora, CO**

**Argonne National Laboratory**



*NREL, CENTER FOR TRANSPORTATION TECHNOLOGIES AND SYSTEMS*

